IN THE UNITED STATES PATENT AND TRADEMARK OFFICE
BEFORE THE BOARD OF PATENT APPEALS AND INTERFERENCES

Applicants: T. KAJI, et al.

Application No.: 10/808,559

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For: A PLASMA PROCESSING APPARATUS

Art Unit: 1763

Examiner: A. Crowell **CONF. No. 4764**

Notice of Appeal filed: June 12, 2007

RE-SUBMITTED APPELLANT'S BRIEF ON APPEAL

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April 7, 2008

Sir:

In response to the Notification of Non-Compliant Appeal Brief, mailed March 5, 2008, and to the Final Office Action mailed February 15, 2007, the present Appellants Brief is respectfully re-submitted under 37 CFR §41.37, in conjunction with the Appeal of the above-identified application. It is noted, in response to paragraph 9 of the Notification, that there are no briefs rendered by the Court or the Board in any proceedings identified in the Related Appeals and Interferences section. A separate Related Proceedings Appendix D is attached.

I. Real Party of Interest

The Real Party of Interest is Hitachi, Ltd. of Japan.

II. Related Appeals and Interferences

None.

III. Status of Claims :

Claims 8-10, 12-25 and 27-38 are pending in this application and are corrently rejected. A copy of these claims which are on appeal appear in **Appendix A**. Claims 1-7, 11 and 26 have been cancelled.

IV. Status of Amendments :

The last amendment filed in this application was an Amendment After Final Rejection Pursuant to 37 CFR §1.116, filed on August 28, 2007 in response to the February 15, 2007 Final Office Action. Following the filing of the August 28, 2007 amendment, applicants received an Advisory Action mailed September 20, 2007, indicating that the August 28, 2007 Amendment would be entered for purposes of Appeal, but that the claims 8-25 and 27-38 remained rejected. No amendment has been filed since receipt of the September 20, 2007 Advisory Action.

V. Summary of Claimed Subject Matter :

The present invention is directed to an improved arrangement for a plasma processing apparatus for plasma processing of samples, such as semiconductor wafers, which samples include an insulator film.

Before discussing the claimed invention, a general introduction will be given to the invention by reference to the disclosure of the parent USP 6,197,151 (which is identical to the present application disclosure). A copy of the parent USP 6,197,151 is provided in **Appendix B**, and reference is made to this disclosure solely for purposes of convenience for the Board Members and the Examiner.

Referring first to Fig. 1, a vertical cross-sectional view of a first embodiment of the plasma etching apparatus of the present invention is shown. As discussed beginning on column 12, line 30 et seq., of the parent USP 6,197,151, a processing chamber 10 of a vacuum container is provided with a pair of opposed electrodes formed of an upper electrode 12 and a lower electrode 15. A sample 40 can be mounted on the lower electrode 15 for processing. A high-frequency power source 16 is provided to supply high-frequency energy to the upper electrode 12. As discusssed on column 14, line 23 et seq., high-frequency electric power of between 30 Mhz. to 300 Mhz. can be provided by this high-frequency electric power source 16. On the other hand, the lower electrode 15 is connected to a pulse bias electric power source 17, as discussed on column 14, lines 30 et seq.

In order to provide gas to the processing chamber 10, a gas introducing chamber 34 is provided with a gas diffusion plate 32 for diffusing gas in a desired distribution (as discussed on column 12, line 58 et seq.). Holes 38 are provide in the upper electrode 12 in an upper electrode cover 30, formed over the upper electrode

12, to permit the gas to flow into the processing chamber 10. In addition, as an important feature of the invention, to be discussed in detail hereinafter :

> "A discharge confining ring 37 is provided in the processing chamber 10 <u>to increase plasma density and make the reaction inside the processing chamber uniform. " (Column 13, lines 3-6).</u>

As can also be seen in Fig. 1, this discharge confining ring 37 serves to separate the vacuum processing chamber 10 from an outer chamber. A small gap is included in the discharge confining ring to permit evacuating the processing gas from the vacuum processing chamber to the outer chamber.

The present invention is fundamentally directed to a problem noted, for example, in column 2, line 53 et seq., of the disclosure of the parent USP 6, 197,151. Specifically:

> "However, in the two-frequency exciting method or the MRIE method described above, it is difficult to stably produce a plasma having a desired density higher than 5×10^{10} cm^{-3} under a pressure condition lower than 4 Pa."

In particular, in accordance with the present invention, as discussed above from column 13, line 3 et seq., the discharge confining ring 37 is particularly designed to permit increasing the plasma density and to make the reaction inside the processing chamber uniform. As will be discussed below, the material of the discharge confining ring, as well as the material of the electrode cover 30 and a susceptive cover 39 are all formed of material appropriate to minimize contamination within the plasma processing chamber. Accordingly, the following discussion regarding the claimed features all relates, in one way or another, to the three features of:

1) increasing plasma density within the vacuum processing chamber;

2) decreasing contamination within the vacuum processing chamber from the plasma etching process;

3) maintaining uniform reaction within the plasma processing chamber.

Turning to the claimed subject matter, each of the independent claims 8, 10, 19, 21, 27 and 28 defines at least the two features of the electrode cover being made of silicon and the discharge confining means being comprised of SiC defining or surrounding the vacuum processing chamber and including the function of "increasing plasma density in the plasma processing chamber." As such, each of the independent claims 8, 10, 19, 21, 27 and 28 define at least two of the above-noted features of designing the discharge confining means (and the electrode cover) to increase the plasma density within the vacuum processing chamber and to decrease contamination from etching.

More specifically, the discharge confining means defined in each of the independent claims can be read on the structure shown in Fig. 1 in which, with the exception of a small gap in the center of the discharge confining means, the discharge confining means completely encloses the vacuum processing chamber to produce an enclosed structure (together with the upper and lower electrodes) to permit the increasing of the plasma density within the vacuum processing chamber 10. As noted above, and discussed on column 2, line 53 et seq. and other places in the Specification, prior art structures have had problems with providing high plasma density, particularly at low pressures. As such, as discussed in column 13, line 3 et seq., the discharge confining means of the present invention is specifically defined to substantially completely enclose the vacuum processing chamber (with the exception of a small gap for evacuation) so that the plasma density can be increased to the desired level.

In addition, the electrode cover is made of silicon and the discharge confining means is comprised of SiC specifically to reduce contaminants which would otherwise occur if different materials, such as silica or quartz, such as found in a number of the references, were used. With regard to this, a Declaration by Dr. Shinichi Tachi is provided in the Evidence Appendix. This Declaration, which was submitted during the prosecution of the present application with the February 17, 2007 Amendment, discusses the importance of using materials which do not include Oxygen for forming the electrode cover, the susceptive cover and the discharge confining means in the present invention. In particular, as discussed by Dr. Tachi, the use of materials such as quartz or silica, found, for example, in a number of the cited references, including the primary reference to Lenz (USP 5,534,751) serve to release Oxygen into the plasma. This, as noted by Dr. Tachi, will degrade the etching results. Therefore, each of the independent claims specifically defines that the electrode cover is made of silicon and the discharge confining means is comprised of SiC so as to avoid this problem of contamination of the plasma.

A second feature of the present invention can be found in independent claims 8 and 10 and dependent claims 29-32. Specifically, these claims define that the discharge confining means not only defines or surrounds the vacuum processing chamber, but also serves to separate the vacuum processing chamber from the outer chamber, as shown in Fig. 1.

A third feature of the present invention, defined in claims 9, 10, 20, 21, 27 and 28-32 is that, in addition to the electrode cover being made of silicon, and the discharge confining means being comprised of SiC, the susceptive cover is also comprised of silicon. This susceptive cover, as shown by the numeral 39 in Fig. 1, is

also comprised of silicon to enhance the reduction of contamination from etching, as discussed above.

A fourth feature of the present invention as discussed above is that the discharge confining means is located to maintain a uniform reaction in the vacuum processing chamber. This is also discussed in column 13, lines 3-6. In particular, the particular structure of the discharge confining means to substantially completely surround and define the vacuum processing chamber serves to create this uniformity within the vacuum processing chamber. This features is specifically defined by the dependent claims 33-38.

A fifth feature of the present invention, defined by the independent claim 28, is the specific feature of:

> "means for generating a plasma with a density of 5×10^{10} cm^{-3} to 5×10^{11} cm^{-3} between said upper electrode and lower electrode to etch a fine pattern on the sample;"

This claimed feature operates in conjunction with the claimed discharge confining means which increases the plasma density within the vacuum processing chamber to achieve the plasma within the claimed range. This claimed range is quite important since, as discussed in column 2, lines 53 et seq., of the specification of the parent USP 6,197,151, prior art devices have failed to achieve this desired range of plasma density. This specific preferred range is discussed, for example, in column 14, line 46 et seq., as noted there, providing a plasma density within this range, in accordance with the present invention, particularly improves microworkability of a large diameter sample.

As a final sixth feature of the present claims, defined by independent claim 27, the present invention is particularly designed to generate a plasma to etch fine

patterns in samples with a diameter of 300 mm or larger. Column 3, lines 18 et seq., particularly note problems which have occurred in the etching of large diameter wafers of 300 mm or larger with prior art devices. By utilizing the specific claimed discharge confining means, it is possible to increase the plasma density to ensure sufficient plasma density and uniformity to properly etch such large diameter samples.

In addition to the above comments, in response to the requirement set forth in the Notification of Non-Compliant Appeal Brief, mailed November 26, 2007, Applicants provide the following mapping of each of the independent claims 8, 10, 19, 21, 27 and 28, by reference to the specification by page and line number and to the drawings.

Beginning with independent claim 8, each of the elements, including the "discharge confining means" can be read on elements shown in Figure 1 (noting that reference to Figure 1 is solely for purposes of providing one example, and not intended to limit the invention only to the specific details of Figure 1). Specifically, the elements of the first paragraph of claim 8 are supported by the vacuum processing chamber 10 processing a sample 40, including an insulator film (e.g. page 18, lines 19j-21) by using a plasma, as described on page 17, lines 18-25. The elements of the second paragraph of claim 8 are supported by the outer chamber 11 surrounding the vacuum processing chamber 10 connected with an evacuation means 18, as described on page 32, lines 1-5. The third paragraph of claim 8 is supported by the gas supplying unit 34 introducing a fluorine-containing processing gas into the vacuum processing chamber 10, as described on page 31, line 24 through page 32, line 1. The fourth paragraph of claim 8 is supported by the upper

electrode 12 and the lower electrode 15 for generating a plasma therebetween and providing the vacuum processing chamber, as described on page 27, lines 18-25. The fifth paragraph of claim 8 is supported by the electrode cover 30 made of silicon being provided at the outer surface of the upper electrode 12, as described on page 28, lines 23-25. Finally, the last paragraph of claim 8 is supported by the discharge confining means 37, comprised of SiC (e.g. see page 40, lines 8-10) for separating the vacuum processing chamber 10 from the outer chamber 11 and for increasing plasma density in the vacuum processing chamber, as described on page 29, lines 7-11.

Turning to independent claim 10, the first paragraph of the claim is supported by the vacuum processing chamber for processing a sample 40, including a insulator phone (e.g. see page 18, lines 19-21) by using a plasma, as described on page 27, lines 18-25. The second paragraph of claim 10 is supported by the gas supplying unit 34 for introducing into the vacuum processing chamber a fluorine-containing processing gas, as described on page 31, lines 24 through page 32, line 1. The third paragraph of claim 10 is supported by the upper electrode 12 and the lower electrode 15 for providing the vacuum processing chamber therebetween, as described on page 27, lines 18-25. The fourth paragraph of claim 10 is supported by the outer chamber 11 surrounding the vacuum processing chamber 10 and connected with an evacuation means 18, as described on page 32, lines 1-5 of the specification. The fifth paragraph of claim 10 is supported by the high frequency electric power source 16 for supplying high frequency energy for generating a plasma between the upper electrode 12 and the lower electrode 15, as described on page 32, lines 5-16. The sixth paragraph of claim 10 is supported by the bias

electric power source 17 connected to the lower electrode 15 to control energy of ions in the plasma, as described on page 31, lines 16-19. The seventh paragraph of claim 10 is supported by the electrode cover 30 comprised of silicon being provided at the outer surface of the upper electrode 12, as described on page 28, lines 23-25. The eighth paragraph of claim 10 is supported by the susceptive cover 39 comprised of silicon being provided near a sample mounting surface of the lower electrode 15, as described on page 40, lines 14-22. Finally, the last paragraph of claim 10 is supported by the discharge confining means 37 comprised of SiC (e.g. see page 40, lines 8-10) for separating the vacuum processing chamber 10 from the outer chamber 11 and for increasing plasma density in the vacuum processing chamber 10, as described on page 29, lines 7-11.

Referring next to independent claim 19, the first paragraph of claim 19 is supported by the vacuum processing chamber 10 for processing a sample 40 including an insulator film (e.g. see page 18, lines 19-21) by use of plasma, as described on page 27, lines 18-25. The second paragraph of claim 19 is supported by the gas supplying unit 34 for introducing into the vacuum container a processing gas containing fluorine, as described on page 31, line 24 through page 32, line 1. The third paragraph of claim 19 is supported the upper electrode 12 and the lower electrode 15 having plasma generated therebetween, as desribed on page 27, lines 18-25. The fourth paragraph of claim 19 is supported by the electrode cover 30 made of silicon being provided at the bottom surface of the upper electrode 12, as described on page 28, lines 23-25. Finally, the last paragraph of claim 19 is supported by the discharge confining means 37 comprised of SiC (e.g. see page 40, lines 8-10) for defining a surrounding vacuum processing chamber 10 in the vacuum

container 10 in the space between the upper electrode 12 and the lower electrode 15 for increasing plasma density in the vacuum processing chamber, as described on page 29, lines 7-11.

Referring next to independent claim 21, the first paragraph of the claim is supported by the vacuum container 10 for processing a sample 40 including an insulator film (e.g. see page 18, lines 19-21) through use of a plasma, as described on page 27, lines 18-25. The second paragraph of claim 21 is supported by the gas supply unit 34 for introducing into the vacuum container 10 a processing gas containing fluorine, as described in page 31, line 24 through page 32, line 1. The third paragraph of claim 21 is supported by the upper electrode 12 and the lower electrode 15 for defining a vacuum processing chamber therebetween, as described on page 27, lines 18-25. The fourth paragraph of claim 21 is supported by the high frequency electric power source 16 for supplying high frequency energy for generating plasma in the vacuum processing chamber 10, as described on page 32, lines 5-16. The fifth paragraph of claim 21 is supported by the bias electric power source 17 connected to the lower electrode 15 to control the energy of ions on the plasma, as described on page 31, liens 16-19. The sixth paragraph of claim 21 is supported by the electrode cover 30 made of silicon being provided at the bottom surface of the upper electrode 12, as described on page 28, lines 23-25. The seventh paragraph of claim 21 is supported by the susceptive cover 39 made of silicon provided around a sample mounting surface of the lower electrode 15, as described on page 40, lines 14-22. The final paragraph of claim 21 is supported by the discharge confining means 37 made of SiC (e.g. see page 40, lines 8-10) and for surrounding the vacuum processing chamber in the vacuum container 10 and for

increasing plasma density in the vacuum processing chamber, as described on page 29, lines 7-11.

The first paragraph of the independent claim 27 is supported by the vacuum container 10 for processing a sample 40 including an insulator (e.g. see page 18, lines 19-21) by use of a plasma, as described on page 27, lines 18-25. The second paragraph on claim 27 is supported by the upper electrode 12 and the lower electrode 15 having plasma generated therebetween, as described on page 27, lines 18-25. The third paragraph of claim 17 (e.g. beginning with “a gas supplying unit”) is supported by the gas supplying unit 34 for introducing into the vacuum container 10 a processing gas containing fluorine, as described on page 31, line 24 through page 32, line 1. The “means for generating plasma between the upper electrode and the lower electrode to etch a fine pattern on a sample having a diameter of 300 mm or more” of the fourth paragraph of claim 27 can be read on the high frequency power source 16 connected to the upper electrode 12, as described on page 33, lines 6-16 as well as the discussion on page 10, lines 12-18 regarding etching a fine pattern on a sample having a diameter of 300 mm or more. The fifth paragraph of claim 27 is supported by the bias electric power source 17 connected to the lower electrode 12 to control energy of ions in the plasma, as described on page 31, lines 16-19. The sixth paragraph of claim 27 is supported by the discharge confining means 37 comprised of SiC (e.g. see page 40, lines 8-10) for defining a vacuum processing chamber 10 in the space between the upper electrode 12 and the lower electrode 15 and the vacuum container 10 and for increasing plasma density in the vacuum processing chamber, as described on page 29, lines 7-11. The seventh paragraph of claim 27 is supported by the electrode cover 30 provided a bottom surface of the

upper electrode 12, wherein the electrode cover is made of silicon and includes holes to pass the processing gas, as described on page 28, line 23 through page 29, line 4. The last paragraph of claim 27 is supported by the susceptive cover 39 made of silicon provided around a sample mounting surface of the lower electrode 15, as described on page 40, lines 14-22.

The first paragraph of independent claim 28 is supported by the vacuum container 10 of Figure 1 for processing a sample 40 including an insulator film (e.g. see page 18, lines 19-21) by use of a plasma, as described on page 27, lines 18-25. The second paragraph of claim 28 is supported by the upper electrode 12 and the lower electrode 15 having plasma generated therebetween, as described on page 27, lines 18-25. The third paragraph of claim 28 (beginning with "a gas supplying unit") is supported by the gas supplying unit 34 for introducing into the vacuum container 10 a processing gas containing fluorine, as described on page 31, line 24 through page 32, line 1. The means for generating a plasma defined in the fourth paragraph of claim 28 is supported by the high frequency power source connected to the upper electrode 12 to generate a plasma with a density between $5 \times 10^{10} cm^{-3}$ to $5 \times 10^{11} cm^{-3}$ to etch a fine pattern on the sample, as described on page 33, lines 6-16 and page 10, lines 12-8. The fifth paragraph of claim 28 is supported by the bias electric power source 17 connected to the lower electrode 15 to control energy of ions in the plasma, as described on page 31, lines 16-19. The sixth paragraph of claim 28 is supported by the discharge confining means 37 comprised of SiC (e.g. see page 40, lines 8-10) for defining a vacuum processing chamber 10 in the space between the upper electrode 12 and the lower electrode 15 and for increasing plasma density in the vacuum processing chamber, as described on page 29, lines

7-11. The seventh paragraph of claim 28 is supported by the electrode cover 30 provided at the bottom surface of the upper electrode 12, wherein the electrode cover is made of silicon and includes holes to pass the processing gas, as described on page 28, line 23 through page 29, line 4. Finally, the last paragraph of claim 28 is supported by the susceptive cover 39 comprises of silicon provided around the sample mounting surface of the lower electrode 12 as described on page 40, lines 14-22.

VI. Grounds of Rejection To Be Reviewed On Appeal:

Claims 8, 13, 16, 19, 24, 25, 29, 33 and 35 are rejected under 35 USC §103(a) as being unpatentable over Lenz et al (USP 5,534,751) in view of Ohmi (USP 5,272,417) and Lenz et al (USP 5,569,356).

Claims 9-12, 14-15, 17-18, 20-23, 30, 34 and 36 are rejected under 35 USC §103(a) as being unpatentable over Lenz et al (USP 5,534,751) in view of Ohmi (USP 5,272,417) and Lenz et al (USP 5,569,356) as applied to claims 8, 13, 16, 19, 24 and 25 above, and further in view of Steger et al (USP 5,494,523) or Ogasawara et al (JP 07-135200).

Claims 27, 28, 31, 32, 37 and 38 are rejected under 35 USC §103(a) as being unpatentable over Lenz et al (USP 5,534,751) in view of Ohmi (USP 5,272,417), Lenz et al (USP 5,569,356), Steger et al (USP 5,494,523) or Ogasawara et al (JP 07-135200) as applied to claims 9-12, 14-15, 17-18, and 20-23 above, and further in view of Koshiishi et al (USP 5,919,332) and Lenz et al (USP 5,609,720).

VII. ARGUMENTS

As discussed above, each of the independent claims 8, 10, 19, 21, 27 and 28, together with the other listed claims 9, 20, 29-38 define one or more of the above-noted six features of the invention, as will be discussed below. The other dependent claims stand or fall with these listed claims.

A) 35 U.S.C. §103(a) Rejection of claims 8, 13, 16, 19, 24, 25, 29, 33 and 35 based on Lenz '751, Ohmi and Lenx '356

Beginning with the rejection of independent claims 8 and 19 and their respective dependent claims over the combination of Lenz '751, Ohmi and Lenz '356, page 3 of the final Office Action relies on the Lenz '751 reference for teaching the claim limitations regarding a discharge confining means separating a vacuum chamber from an outer chamber "for increasing plasma density in the vacuum processing chamber." The rejection goes on to argue that, although Lenz fails to teach an electrode cover made of silicon, the Ohmi reference teaches such an electrode cover. Further, the final Office Action goes on to state that, although Lenz '751 fails to teach a discharge confining means made of SiC, the Lenz '356 reference does teach a discharge confining means 34 made of SiC.

In response, applicants respectfully submit that a close inspection of the Lenz '751 patent actually leads to the clear conclusion that this reference is not capable of meeting the claimed function of a discharge confining means for increasing the plasma density within the vacuum processing chamber. As an initial impression from Fig. 1 of the Lenz '751 patent, it would appear that it is similar to the discharge confining means 37 of Fig. 1 of the present application. However, Fig. 2 shows a much more accurate depiction of the confining assembly of the Lenz '751 patent

which is comprised of a plurality of quartz circular rings 32 separated from one another by washers 34 to define a plurality of circumferential slots 31 "for which the spent gasses within the inner action space 17 exit to flow out of the chamber 12." Column 6, lines 33 and 34). In particular, from Fig. 2, it is quite clear that the circumferential slots 31 will comprise a very large area of the confinement ring 30.

Further, a careful reading of the purpose of the Lenz '751 patent leads to the conclusion that the term "confinement" as used in Lenz '751 is not meant in any way to physically confine the plasma to increase the plasma density, but, instead, to specifically structure the ring assembly so that particles exiting from the processing chamber will be neutralized so that the plasma does not extend outside of the ring assembly 30. This is quite clearly stated in column 2, lines 7 et seq., as follows:

> "To this end, the present invention involves confining the plasma discharge to the inner action space between the electrodes by surrounding the inner action space with confining assembly <u>defining a plurality of passages extending through the confinement assembly from an inner to an outer surface, the passages being proportioned to neutralize charge particles created in the plasma when the charge particles pass through the passages.</u> <u>...</u>In a typical embodiment, six rings were used to form five distinctive parallel circumferential slots therebetween in addition to the slots above and below. <u>Moreover, the slots that are formed are appropriately proportioned such that the distance a charged gas particle from the plasma must travel in a slot in exiting it is substantially longer than the mean-free path of the particle so that most exiting particles make at least one collision with the walls of the slot. These collisions with the slot walls neutralize the charges on the particles and so the exiting particles are neutral.</u> Accordingly, the tendency for a discharge outside the inner action space is essentially eliminated. "

In other words, the purpose of the Lenz '751 patent is specifically to define slots 31, acting with the rings 32, to prevent the plasma from being generated outside of the confinement area, <u>not to increase the plasma density within the confinement area, as required by the present means-plus-function claim language.</u> Viewing Fig. 2 of the Lenz '751 patent makes it very clear that the slots 31 represent

such a large portion of the confinement ring structure 30, that a very substantial particle flow will exist which would effectively prevent increasing plasma density within the confinement region. Further, absolutely nothing in Lenz '751 at all suggests that it was intended to actually increase plasma density with this structure. Instead, the goal of Lenz is to neutralize particles that escape from the confinement chamber so that they are neutralized once they leave this confinement chamber. Therefore, the fundamental feature of each of the independent claims 8 and 19, rejected in the first ground of rejection of means for increasing the plasma density in the vacuum processing chamber is lacking from the Lenz '751 structure.

In addition, as recognized in the Office Action, Lenz '751 fails to teach the use of SiC for the discharge confining means. Instead, it is very clearly stated at several locations throughout the Lenz patent that silica or quartz rings are used. This is discussed in the first line of the Abstract, for example. (Column 6, line 16 et seq., clearly states that the stack of circular rings is formed of "a dielectric that preferably is high quality fused silica or quartz." A number of the Lenz claims also specifically define the formation with dielectric material or quartz. As such, the primary reference of Lenz '751 will suffer from the specific problem of oxygen degradation of the plasma noted by Dr. Tachi's Declaration found in the Evidence Appendix.

The Office Action refers to Lenz '356 as teaching a discharge confining means 34 made of SiC. <u>With regard to this, applicants respectfully submit that the fact that Lenz '751 and Lenz '356 have the same lead inventor (i.e., Lenz), and that the Lenz '356 was actually filed on May 19, 1995, before the July 10, 1995 filing date of the application leading to the '751 patent, clearly if Lenz had any intention of utilizing SiC as the discharge ring material in the '751 patent, this would have been</u>

disclosed as an alternative. It is urged that the fact that the Lenz '751 patent is completely devoid of any suggestion of SiC leads to the conclusion that Lenz regarded SiC as inappropriate for his discharge ring 30. This is not at all surprising given the fact that the discharge confining ring 30 taught by Lenz '751 has a very specific purpose of neutralizing charges by particles escaping through its numerous slots 31. Evidentially, the use of "highly fused silica or quartz" (column 6, line 18) was an important requirement for the ring structure of the '751 patent. Therefore, it is respectfully submitted that the failure of Lenz to disclose SiC as an alternative in the '751 patent leads to a clear teaching away from the modification of the Lenz '751 structure in this manner. And, in any event, even if one were to use SiC in the Lenz '751 structure, the end result would still be completely different from the claimed discharge confinement means since, as noted above, the ring structure of the '751 patent is incapable of meeting the claim limitation of means for increasing plasma density within the vacuum processing chamber.

B) 35 U.S.C. §103(a) Rejection of Claims 9-12, 14, 15, 17-18, 20-23, 30, 34 and 35 based on Lenz '751, Ohmi, Lenz '356, Steger and/or Ogasawara

Turning to the rejection of claims 9-12, 14, 15, 17-18, 20-23, 30, 34 and 36 over the same references of Lenz '751 in view of Ohmi and Lenz '356, together with Steger and Ogasawara, it is noted, firstly, that Steger and Ogasawara add absolutely nothing to the other three cited references to overcome the shortcomings of these references noted above. It is also noted that each of the other independent claims 10, 21, 27 and 28 define the same features noted above for independent claims 8 and 19 in defining over the combination of Lenz '751, Ohmi and Lenz '356.

Turning to this specific rejection, Steger and Ogasawara are both cited for teaching a susceptive cover comprised of silicon. Although these references are of general interest concerning susceptive covers, the fact remains that the rejected claims define an overall combination of elements which include an electrode cover and a susceptive cover of silicon, together with a discharge confinement means comprised of SiC for increasing plasma density within a vacuum processing chamber. Even if the reference to Lenz '751 were modified to include the susceptive covers of Steger and Ogasawara, the combination would still not include a discharge confinement means comprised of SiC to increase plasma density within a vacuum processing chamber. Therefore, reconsideration and removal of this rejection is also respectfully requested.

<u>C) 35 U.S.C. §103(a) Rejection of Claims 27, 28, 31, 32, 37 and 38 over Lenz '751, Ohmi, Lenz '356, Steger, Ogasawara, Koshiishi and Lenz '720</u>

Turning next to the rejection of claims 27, 28, 31, 32, 37 and 38 over the Lenz '751 patent, Ohmi, Lenz '356, Steger, Ogasawara and further in view of Koshiishi and Lenz '720, the Koshiishi patent is cited to teach the claimed plasma density range between $5 \times 10^{10} cm^{-3}$ to $5 \times 10^{11} cm^{-3}$. Lenz '720 is cited with regard to processing of chambers having a diameter of 300 mm. Regarding this, it is again noted that nothing in either Koshiishi or Lenz '720 overcomes the fundamental failings of the other references to meet the claim limitations concerning the discharge confining means comprised of SiC for increasing plasma density within the vacuum processing chamber.

With particular regard to the feature of the plasma density being in the claimed range (as defined in claim 28), as noted above, this claimed range is

important in the present invention because it is a plasma density range which was not achieved by prior art structures, particularly at low plasma densities. With regard to the distinctions over Koshiishi, it is noted that the present claims are specifically directed to <u>the discharge confining means being comprised of SiC for increasing plasma density in the plasma processing chamber to achieve this claimed range.</u> It is respectfully submitted that nothing in Koshiishi suggests the structuring of the discharge confining means, comprised of SiC, to achieve this particular result. Further, it would take a complete restructuring of the primary Lenz '751 ring structure 30, with its numerous slots 31, to be able to achieve the claimed increase in plasma density to arrive at this claimed range. Koshiishi's only teachings concerning any plasma confinement structure are the formation of the upper electrode 31 "of transparent quartz or the like" (column 14, line 18). As defined in column 12, line 41 et seq., this upper insulating member 31 is used to prevent the plasma from being directly diffused towards inner walls of the processing container 3. <u>However, absolutely nothing in Koshiishi suggests that the upper insulator 31 would serve to meet the limitation of a discharge confining means for increasing plasma density within the processing chamber.</u> Also, given the fact that it covers only the upper half of the vacuum processing chamber, obviously there is completely insufficient coverage to increase the plasma pressure within the processing chamber, as required by the present means-plus-function claim language found in each of the independent claims 8, 10, 19, 21, 27 and 28. Therefore, it is respectfully submitted that the combination of the plasma density and the discharge confining means for increasing plasma density set forth in claim 28 is neither taught nor suggested by the combination relying on Koshiishi set forth in the rejection.

As for the Lenz '720 patent, although this teaches the use of processing wafers of 300 mm or larger, nothing in this reference suggest the claim discharge confining means for increasing plasma density within the vacuum processing chamber. As discussed above, large wafers of 300 mm or more suffer from particular problems of uniformity due to their large size. independent claim 27 is specifically directed to the combination of the claimed discharge confining means and the ability of the claimed invention to etch fine patterns on wafers of 300 mm or larger. Again, there is nothing in the Lenz '720 patent which suggests the particular design of a discharge confining means to achieve the sufficient pressure and uniform etching of such a large diameter wafer. Therefore, also Lenz '720 operates on wafers of 300 mm or larger, again, there is nothing to suggest the complete modification of Lenz '751 which would be necessary to modify that structure to operate as a discharge confining means for increasing plasma density within a vacuum processing chamber.

The above discussion pertains to all of the six features originally discussed in the preceding section of the claimed subject matter except for the two features of the discharge confining means separating the vacuum processing chamber from the outer chamber (claims 8, 10 and 29-32) and a discharge confining means being located to maintain uniform reaction in the vacuum processing chamber (dependent claim 33 – 38). With regard to this, although the Lenz '751 patent has been cited for teaching separation of a vacuum processing chamber from an outer chamber, it is noted that this "separation" is by a ring structure which is very largely comprised of slots 31 which will significantly reduce any effective separation of the vacuum processing chamber from the outer chamber. Again, the concept of Lenz '751 is not

to confine the plasma physically within the vacuum processing chamber (by the separation achieved in the present claimed invention), but, instead, to neutralize the many escaping particles from the vacuum processing chamber to the outer chamber. Therefore, it is respectfully submitted that the claimed combination of elements will not teach or suggest the claimed discharge confining means separating a vacuuming processing chamber from an outer chamber.

Similarly, it is respectfully submitted that nothing in the cited prior art teaches the features defined by dependent claims 33-38 of locating a discharge confining means which increases the plasma density and maintains uniform reactions in the vacuum processing chamber. Concerning this feature, the final Office Action states on page 5, lines 9 et seq., that:

> "With respect to claims 33 and 35, the apparatus of Lenz et al further wherein the discharge confining means 30 is located for maintaining a uniform reaction in the vacuum processing chamber (column 3, lines 23-28)."

It is assumed that the Lenz et al being referred to Lenz '751. Column 3, lines 23-28 of Lenz '751 states:

> "Viewed from another aspect, the present invention is directed to plasma etching apparatus that includes plasma confinement. The plasma etching apparatus comprises means for housing a gaseous medium useful for etching, a parallel pair of electrodes, and a stack of at least three spaced-apart rings."

<u>It is respectfully submitted that absolutely nothing in this language from the Lenz '751 teaches or suggests the claimed feature of "the discharge confining means is located for maintaining a uniform reaction in the vacuum processing chamber." Indeed, absolutely nothing is found in this quoted section concerning uniform reactions at all.</u> As noted above, the term "plasma confinement" in Lenz '751 apparently relates to neutralizing charged particles as they exit through the "spaced

apart rings" referred to in column 3, lines 23-28. This apparent large escape of particles certainly would not pertain to either increasing plasma density or maintaining a uniform reaction in the vacuum processing chamber. The structure of Lenz '751 is simply very different from the structure defined by the present discharge confining means. Therefore, particular consideration of these claims 33-38 is also respectfully requested.

VIII. Conclusion:

For the foregoing reasons, appellants request that the Examiner's rejections be reversed.

If the Examiner believes that there are any other points which may be clarified or otherwise disposed of either by telephone discussion or by personal interview, the Examiner is invited to contact Applicants' undersigned attorney at the number indicated below.

An electronic payment covering the Appeal Brief filing fee of $510.00 is being submitted concurrently herewith.

To the extent necessary, Applicants petition for an extension of time under 37 CFR 1.136. Please charge any shortage in fees due in connection with the filing of this paper, including extension of time fees, to the Antonelli, Terry, Stout & Kraus,

LLP Deposit Account No. 01-2135 (Docket No. 520.35237CV4), and please credit any excess fees to such deposit account.

Respectfully submitted,
ANTONELLI, TERRY, STOUT & KRAUS, LLP

By /Gregory E. Montone/
Gregory E. Montone
Reg. No. 28,141

GEM/dks
Attachments: Appendices A, B, C and D.

APPENDIX A

1. – 7. (Canceled)

8. A plasma processing apparatus comprising:

a vacuum processing chamber for processing a sample, including an insulator film, by using plasma;

an outer chamber surrounding the vacuum processing chamber connected with an evacuation means;

a gas supplying unit for introducing into the vacuum processing chamber a fluorine-containing processing gas;

an upper electrode and a lower electrode for generating plasma therebetween and providing the vacuum processing chamber;

an electrode cover made of silicon being provided at the outer surface of the upper electrode; and

a discharge confining means comprised of SiC for separating the vacuum processing chamber from the outer chamber and for increasing plasma density in the vacuum processing chamber .

9. The plasma processing apparatus according to claim 8; the lower electrode having a sample mounting surface; said apparatus further comprising a susceptive cover comprised of silicon near the sample mounting surface.

10. A plasma processing apparatus comprising:

a vacuum processing chamber for processing a sample, including an insulator film, by using plasma;

a gas supplying unit for introducing into the vacuum processing chamber a fluorine-containing processing gas;

an upper electrode and a lower electrode for providing the vacuum processing chamber therebetween;

an outer chamber surrounding the vacuum processing chamber and connected with an evacuation means;

a high frequency electric power source for supplying a high frequency energy for generating plasma between the upper electrode and the lower electrode;

a bias electric power source connected to the lower electrode to control energy of ions in the plasma;

an electrode cover comprised of silicon being provided at the outer surface of the upper electrode;

a susceptive cover comprised of silicon being provided near a sample mounting surface of the lower electrode; and

a discharge confining means comprised of SiC for separating the vacuum processing chamber from the outer chamber and for increasing plasma density in the vacuum processing chamber .

Claim 11. (Canceled)

12. The plasma processing apparatus according to claim 10, wherein the discharge confining means includes at least a gap for evacuating the processing gas from the vacuum processing chamber to the outer chamber.

13. The plasma processing apparatus according to claim 8, wherein the discharge confining means is ring-shaped.

14. The plasma processing apparatus according to claim 9, wherein the discharge confining means is ring-shaped.

15. The plasma processing apparatus according to claim 10, wherein the discharge confining means is ring-shaped.

16. The plasma processing apparatus according to claim 8, wherein the discharge confining means is provided with at least a gap for evacuating the processing gas from the vacuum processing chamber to the outer chamber.

17. The plasma processing apparatus according to claim 9, wherein the discharge confining means is provided with at least a gap for evacuating the processing gas from the vacuum processing chamber to the outer chamber.

18. The plasma processing apparatus according to claim 13, wherein the discharge confining means is provided with at least a gap for evacuating the processing gas from the vacuum processing chamber to the outer chamber.

19. A plasma processing apparatus comprising:

a vacuum container for processing a sample including an insulator film by use of plasma;

a gas supplying unit for introducing into the vacuum container a processing gas containing fluorine;

an upper electrode and lower electrode having plasma generated therebetween;

an electrode cover made of silicon provided at the bottom surface of the upper electrode; and

a discharge confining means comprised of SiC for defining a surrounding vacuum processing chamber in the vacuum container in the space between said upper and lower electrodes and for increasing plasma density in the vacuum processing chamber.

20. The plasma processing apparatus according to claim 19:

wherein said lower electrode includes a sample mounting surface, and further comprising a susceptive cover around the sample mounting surface, and wherein said susceptive cover is also made of silicon.

21. A plasma processing apparatus comprising:

a vacuum container for processing of a sample including an insulator film through the use of plasma;

a gas supplying unit for introducing into the vacuum container a processing gas containing fluorine;

an upper electrode and lower electrode for defining a vacuum processing chamber therebetween;

a high frequency electric power source for supplying a high frequency energy for generating plasma in the vacuum processing chamber;

a bias electric power source connected to the lower electrode to control the energy of ions in the plasma;

an electrode cover made of silicon being provided at the bottom surface of the upper electrode;

a susceptive cover made of silicon provided around a sample mounting surface of the lower electrode; and

a discharge confining means made of SiC for surrounding the vacuum processing chamber in the vacuum container and for increasing plasma density in the vacuum processing chamber.

22. The plasma processing apparatus according to claim 21 further comprising an outer chamber defined within the vacuum container outside of the vacuum processing chamber, said outer chamber being connected with an evacuation means.

23. The plasma processing apparatus according to claim 21 wherein the discharge confining means includes at least a gap for evacuating the processing gas from the vacuum processing chamber to the outer chamber.

24. The plasma processing apparatus as in claim 19 wherein the discharge confining means is ring shaped.

25. The plasma processing apparatus according to claim 19 and further comprising an outer chamber defined in said vacuum container outside of said vacuum processing chamber and wherein the discharge confining means is provided with at least a gap for evacuating the processing gas from the vacuum processing chamber to the outer chamber.

Claim 26. (Canceled)

27. A plasma etching apparatus comprising:

a vacuum container for processing a sample including an insulator film by use of plasma;

an upper electrode and lower electrode having plasma generated therebetween;

wherein said plasma etching apparatus further comprises:

a gas supplying unit for introducing into the vacuum container a processing gas containing fluorine;

means for generating a plasma between said upper electrode and lower electrode to etch a fine pattern on the sample having a diameter of 300 mm or more;

a bias electric power source connected to the lower electrode to control energy of ions in said plasma;

a discharge confining means comprised of SiC for defining a vacuum processing chamber in the space between said upper and lower electrodes in the vacuum container and for increasing plasma density in the vacuum processing chamber;

an electrode cover provided at the bottom surface of the upper electrode, wherein the electrode cover is made of silicon and includes holes to pass the processing gas;

a susceptive cover, made of silicon, provided around a sample mounting surface of the lower electrode.

28. A plasma etching apparatus comprising:

a vacuum container for processing a sample including an insulator film by use of plasma;

an upper electrode and lower electrode having plasma generated therebetween;

wherein said plasma etching apparatus further comprises:

a gas supplying unit for introducing into the vacuum container a processing gas containing fluorine;

means for generating a plasma with a density of 5×10^{10} cm^{-3} to 5×10^{11} cm^{-3} between said upper electrode and lower electrode to etch a fine pattern on the sample ;

a bias electric power source connected to the lower electrode to control energy of ions in said plasma;

a discharge confining means comprised of SiC for defining a vacuum processing chamber in the space between said upper and lower electrodes and for increasing plasma density in the vacuum processing chamber;

an electrode cover provided at the bottom surface of the upper electrode, wherein the electrode cover is made of silicon and includes hole to pass the processing gas; and

a susceptive cover made of silicon provided around the sample mounting surface of the lower electrode.

29. A plasma processing apparatus according to claim 19, wherein the vacuum container includes an outer chamber, connected with an evacuation means, surrounding the vacuum processing chamber, and wherein the discharge confining means is located to serve as means for separating the vacuum processing chamber from the outer chamber.

30. A plasma processing apparatus according to claim 21, wherein the vacuum container includes an outer chamber, connected with an evacuation means, surrounding the vacuum processing chamber, and wherein the discharge confining means is located to serve as means for separating the vacuum processing chamber from the outer chamber.

31. A plasma etching apparatus according to claim 27, wherein the vacuum container includes an outer chamber, connected with an evacuation means, surrounding the vacuum processing chamber, and wherein the discharge confining

means is located to serve as means for separating the vacuum processing chamber from the outer chamber.

32. A plasma etching apparatus according to claim 28, wherein the vacuum container includes an outer chamber, connected with an evacuation means, surrounding the vacuum processing chamber, and wherein the discharge confining means is located to serve as means for separating the vacuum processing chamber from the outer chamber.

33. A plasma processing apparatus according to claim 8, wherein the discharge confining means is located for maintaining a uniform reaction in the vacuum processing chamber.

34. A plasma processing apparatus according to claim 10, wherein the discharge confining means is located for maintaining a uniform reaction in the vacuum processing chamber.

35. A plasma processing apparatus according to claim 29, wherein the discharge confining means is located for maintaining a uniform reaction in the vacuum processing chamber.

36. A plasma processing apparatus according to claim 30, wherein the discharge confining means is located for maintaining a uniform reaction in the vacuum processing chamber.

37. A plasma etching apparatus according to claim 31, wherein the discharge confining means is located for maintaining a uniform reaction in the vacuum processing chamber.

38. A plasma etching apparatus according to claim 32, wherein the discharge confining means is located for maintaining a uniform reaction in the vacuum processing chamber.

Appendix B
USP 6,197,151

US006197151B1

(12) **United States Patent**
Kaji et al.

(10) **Patent No.: US 6,197,151 B1**
(45) **Date of Patent: Mar. 6, 2001**

(54) **PLASMA PROCESSING APPARATUS AND PLASMA PROCESSING METHOD**

(75) Inventors: **Tetsunori Kaji**, Tokuyama; **Shinichi Tachi**, Sayama; **Toru Otsubo**, Fujisawa; **Katsuya Watanabe**, Kudamatsu; **Katsuhiko Mitani**, Hikari; **Junichi Tanaka**, Chiyoda-machi, all of (JP)

(73) Assignee: **Hitachi, Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/564,788**

(22) Filed: **May 5, 2000**

Related U.S. Application Data

(63) Continuation of application No. 08/808,805, filed on Feb. 28, 1997, now Pat. No. 6,129,806.

(30) **Foreign Application Priority Data**

Mar. 1, 1996 (JP) 8-44391
Jan. 20, 1997 (JP) 9-7938

(51) **Int. Cl.**^{7} **H05H 1/00**
(52) **U.S. Cl.** .... **156/345**; 118/723 E; 204/298.37
(58) **Field of Search** .... 156/345; 118/723 E; 204/298.37

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Primary Examiner—Thi Dang
(74) *Attorney, Agent, or Firm*—Antonelli, Terry, Stout & Kraus, LLP

(57) **ABSTRACT**

A plasma processing apparatus comprising a vacuum processing chamber, a plasma generating means including a pair of electrodes, a sample table for mounting a sample to be processed inside the vacuum processing chamber and also serving as one of the electrodes, and a evacuating means for evacuating the vacuum processing chamber, which further comprises a high frequency electric power source for applying an electric power of a VHF band from 50 MHz to 200 MHz between the pair of electrodes; and a magnetic field forming means for forming a static magnetic field or a low frequency magnetic field larger than 10 gausses and smaller than 110 gausses in a direction intersecting an electric field generated between the pair of electrodes and the vicinity by the high frequency electric power source; therein the magnetic field forming means being set so that a portion where a component of the magnetic field in a direction along the surface of the sample table becomes maximum is brought to a position in the opposite side of the sample table from the middle of the both electrodes; an electron cyclotron resonance region being formed between the both electrodes by the magnetic field and the electric field.

5 Claims, 31 Drawing Sheets

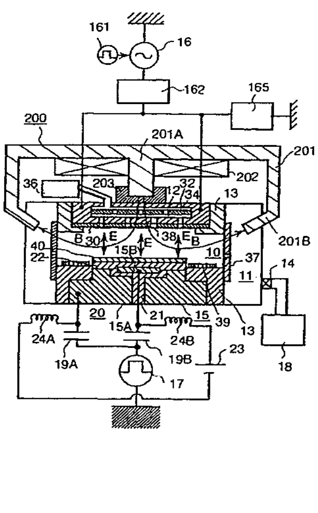


FIG. 1

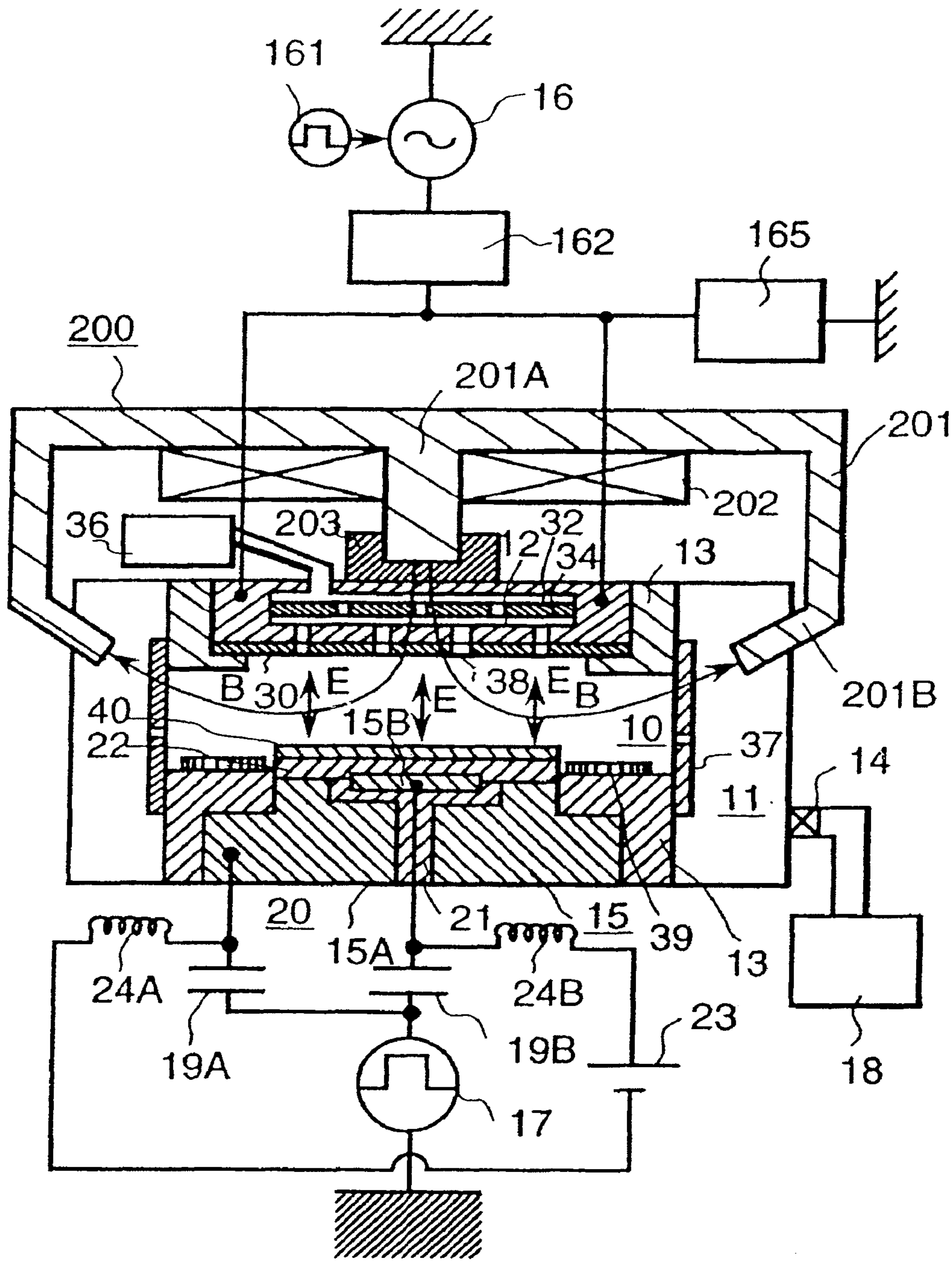

161
16
162
165
200
201A
201
202
36
203
32
12
34
13
B
30
E
38
E
B
201B
40
15B
E
10
37
22
14
11
20
21
15
39
13
15A
24A
24B
23
19A
19B
18
17

FIG. 2

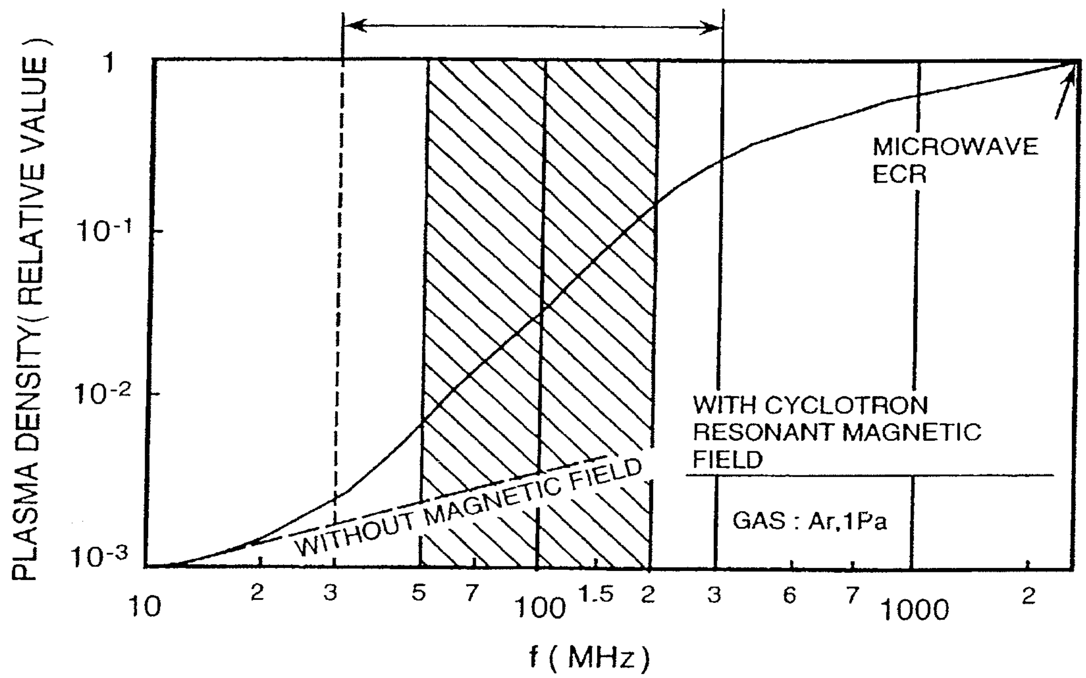

PLASMA DENSITY(RELATIVE VALUE)
1
10-1
10-2
10-3
10
2
3
5
7
100
1.5
2
3
6
7
1000
2
f (MHz)
MICROWAVE
ECR
WITH CYCLOTRON
RESONANT MAGNETIC
FIELD
WITHOUT MAGNETIC FIELD
GAS : Ar,1Pa

FIG. 3

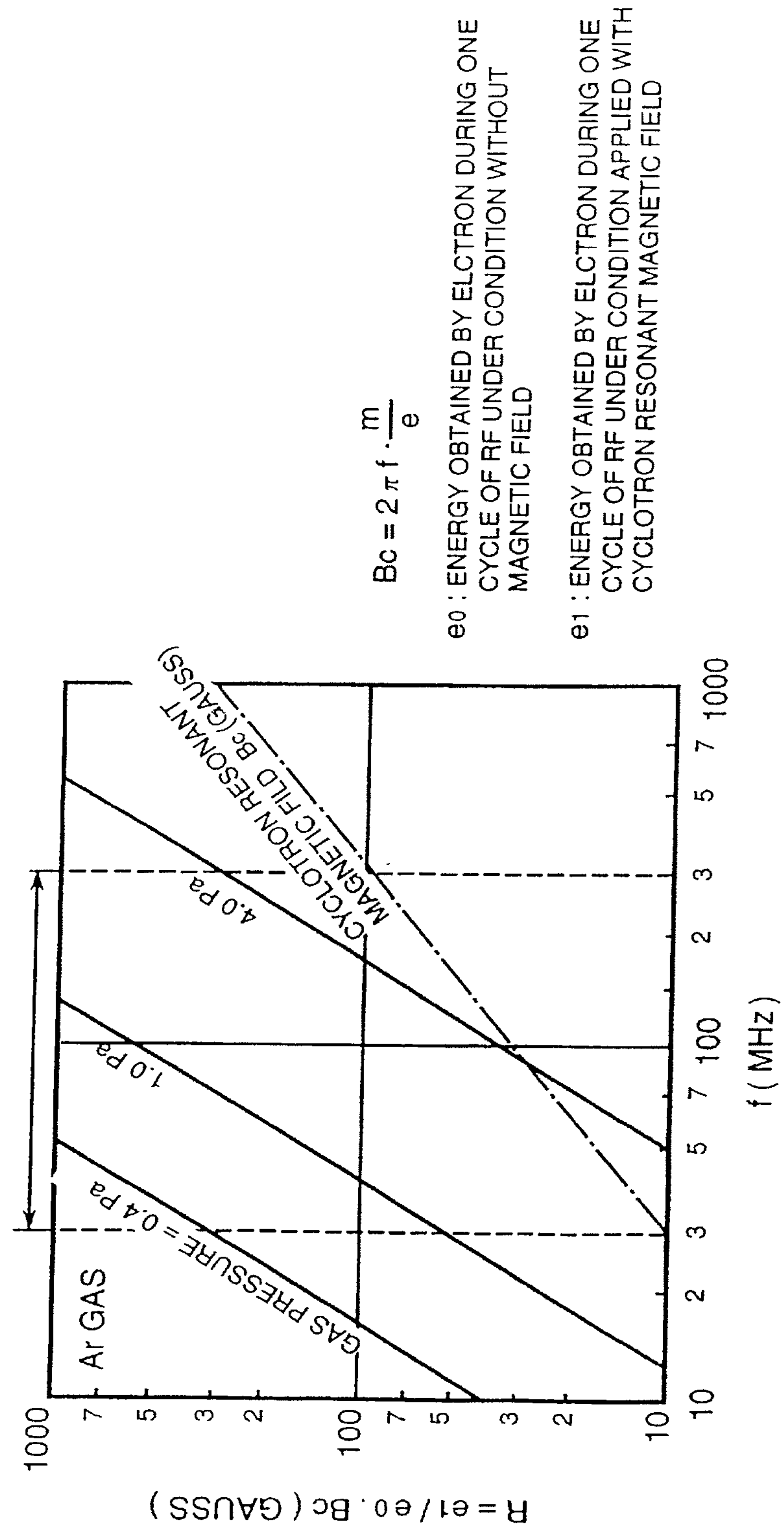
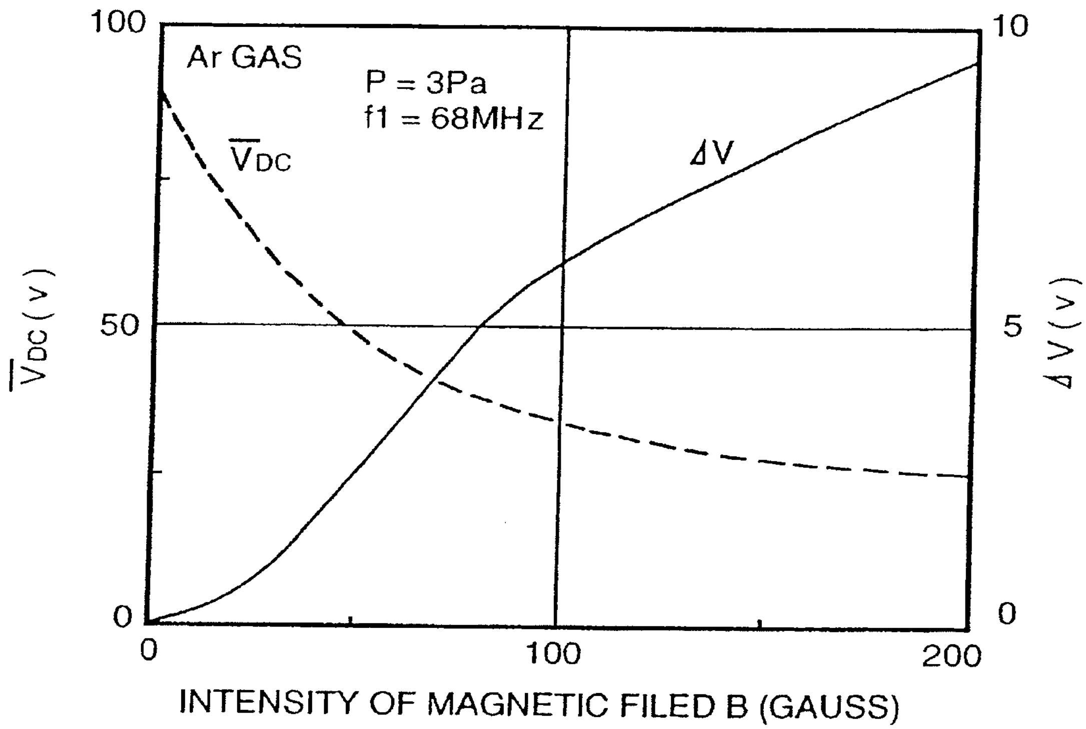

Ar GAS
GAS PRESSURE = 0.4 Pa
1.0 Pa
4.0 Pa
CYCLOTRON RESONANT MAGNETIC FILD Bc (GAUSS)
R = e1 / e0 . Bc (GAUSS)
f (MHz)
$Bc = 2\pi f \cdot \frac{m}{e}$
e0 : ENERGY OBTAINED BY ELCTRON DURING ONE CYCLE OF RF UNDER CONDITION WITHOUT MAGNETIC FIELD
e1 : ENERGY OBTAINED BY ELCTRON DURING ONE CYCLE OF RF UNDER CONDITION APPLIED WITH CYCLOTRON RESONANT MAGNETIC FIELD

FIG. 4



100
50
0
10
5
0
Ar GAS
P = 3Pa
f1 = 68MHz
$\overline{V}_{DC}$
ΔV
$\overline{V}_{DC}$ (v)
ΔV (v)
0
100
200
INTENSITY OF MAGNETIC FILED B (GAUSS)

FIG. 5

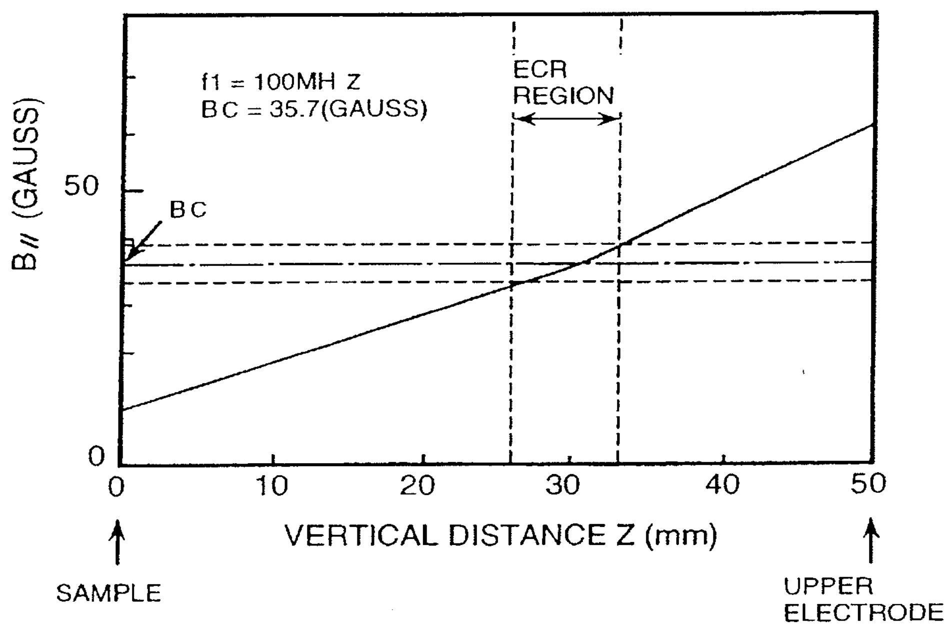

f1 = 100MH Z
BC = 35.7(GAUSS)
ECR
REGION
BC
B// (GAUSS)
50
0
0
10
20
30
40
50
VERTICAL DISTANCE Z (mm)
SAMPLE
UPPER
ELECTRODE

FIG. 6

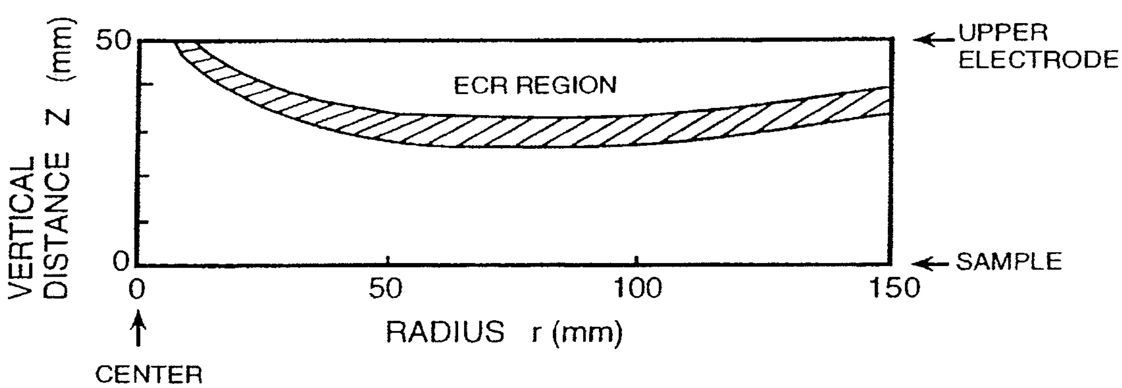

ECR REGION
VERTICAL
DISTANCE Z (mm)
50
0
0
50
100
150
RADIUS r (mm)
CENTER
UPPER
ELECTRODE
SAMPLE

FIG. 7(A)

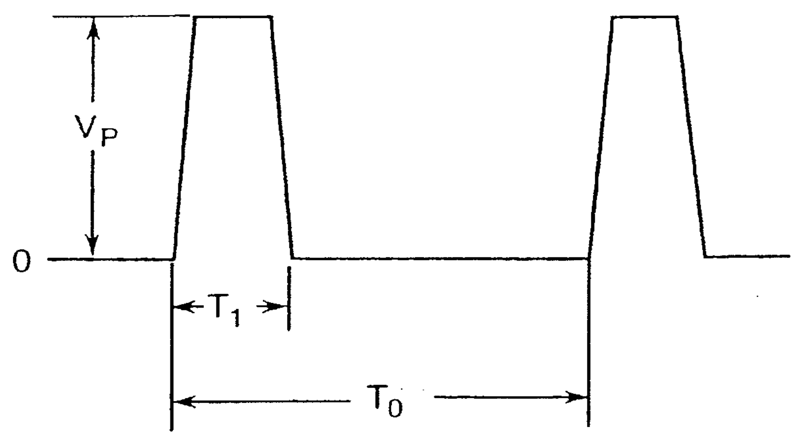
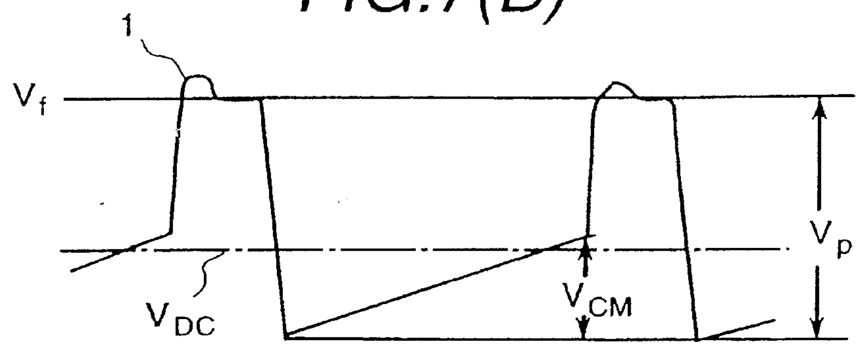


FIG. 7(B)



$$V_{CM} = \frac{q}{c} = \frac{i_i \cdot (T_0 - T_1)}{(\varepsilon_\gamma \, \varepsilon_0 / d) \times K}$$

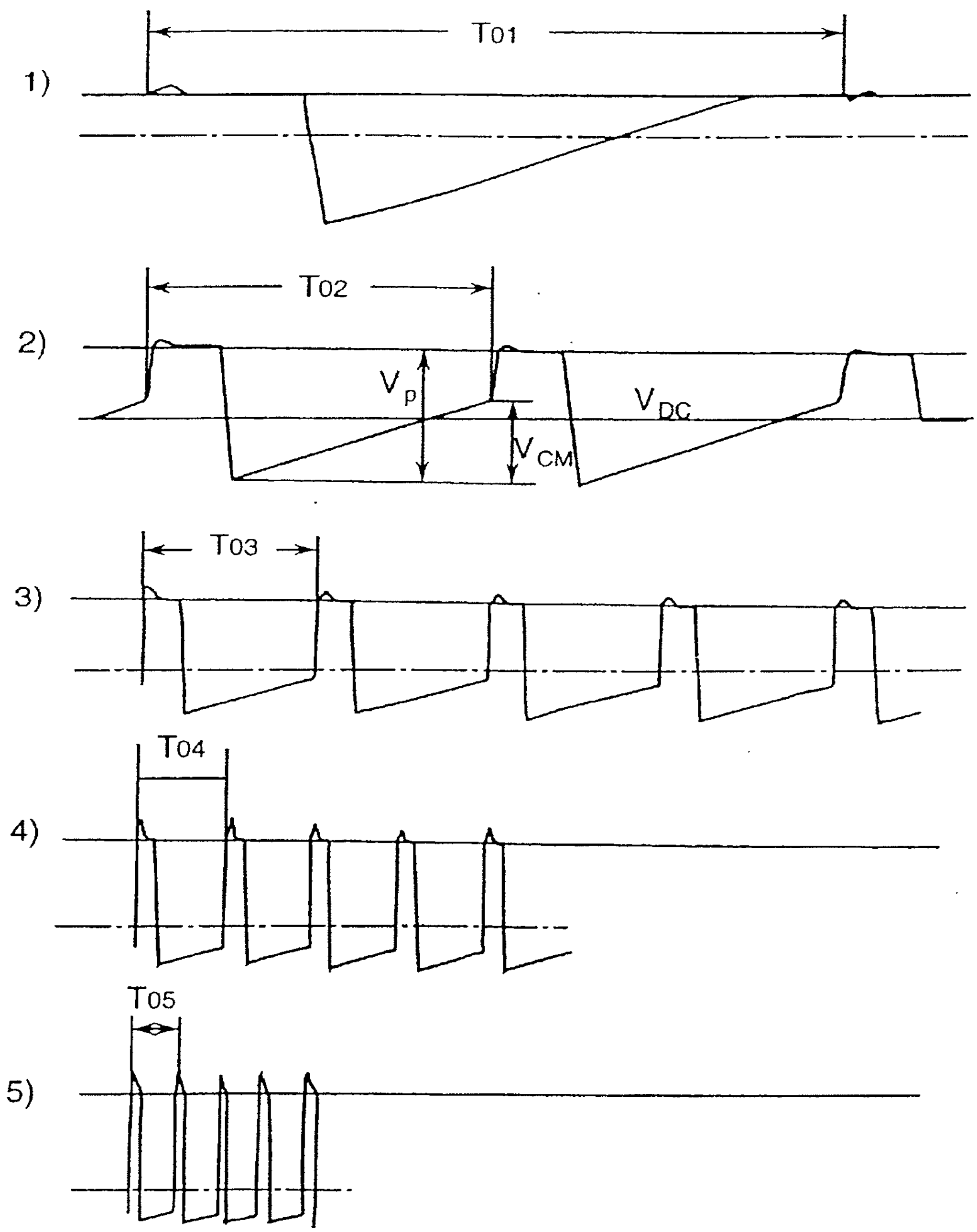
i_i : ION CURRENT DENSITY

ε_γ : SPECIFIC DIELECTRIC CONSTANT OF ELECTROSTATIC ATTRACTING FILM

d : THICKNESS OF ELECTROSTATIC ATTRACTING FILM

K : ELECTRODE COVERING RATIO OF ELECTROSTATIC ATTRACTING FILM

FIG. 8



T01 : T02 : T03 : T04 : T05 = 16 : 8 : 4 : 2 : 1

FIG. 9

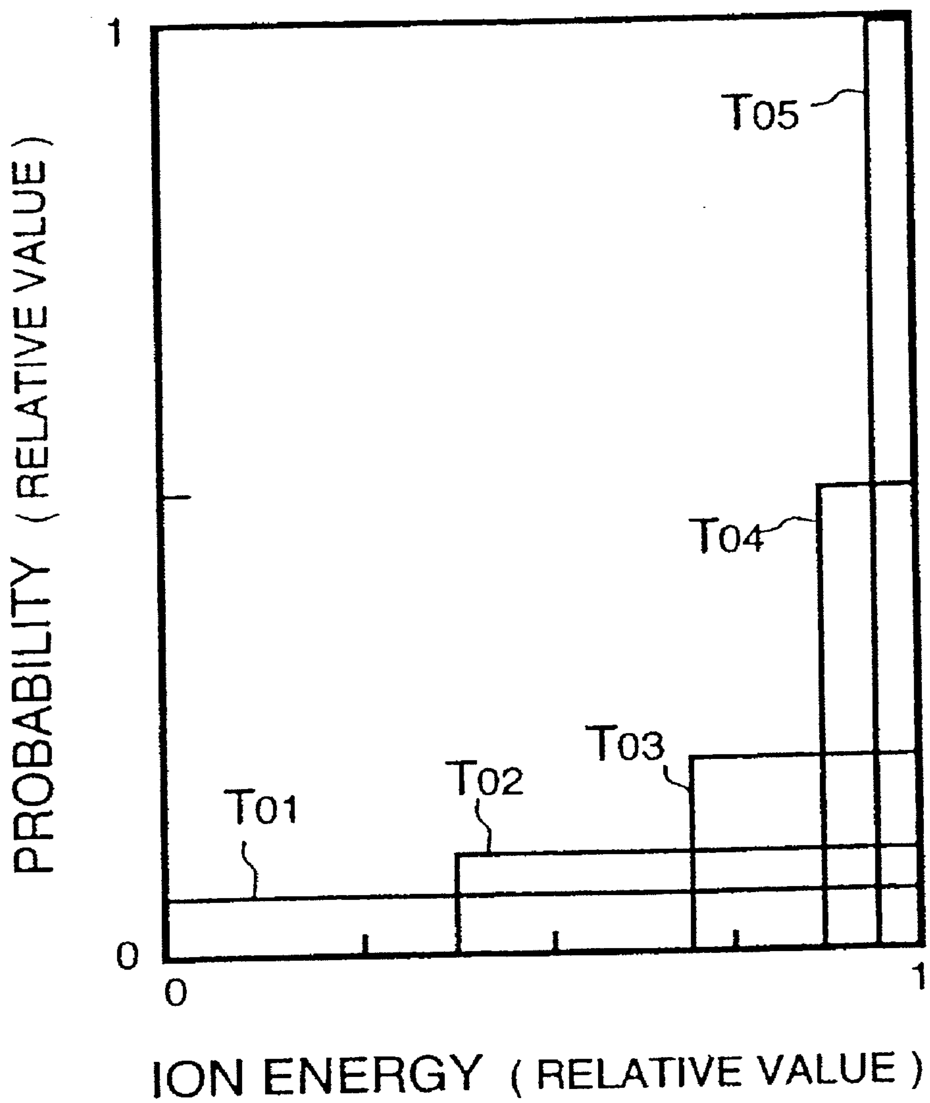

1
0
0
1
T01
T02
T03
T04
T05
PROBABILITY (RELATIVE VALUE)
ION ENERGY (RELATIVE VALUE)

FIG. 10

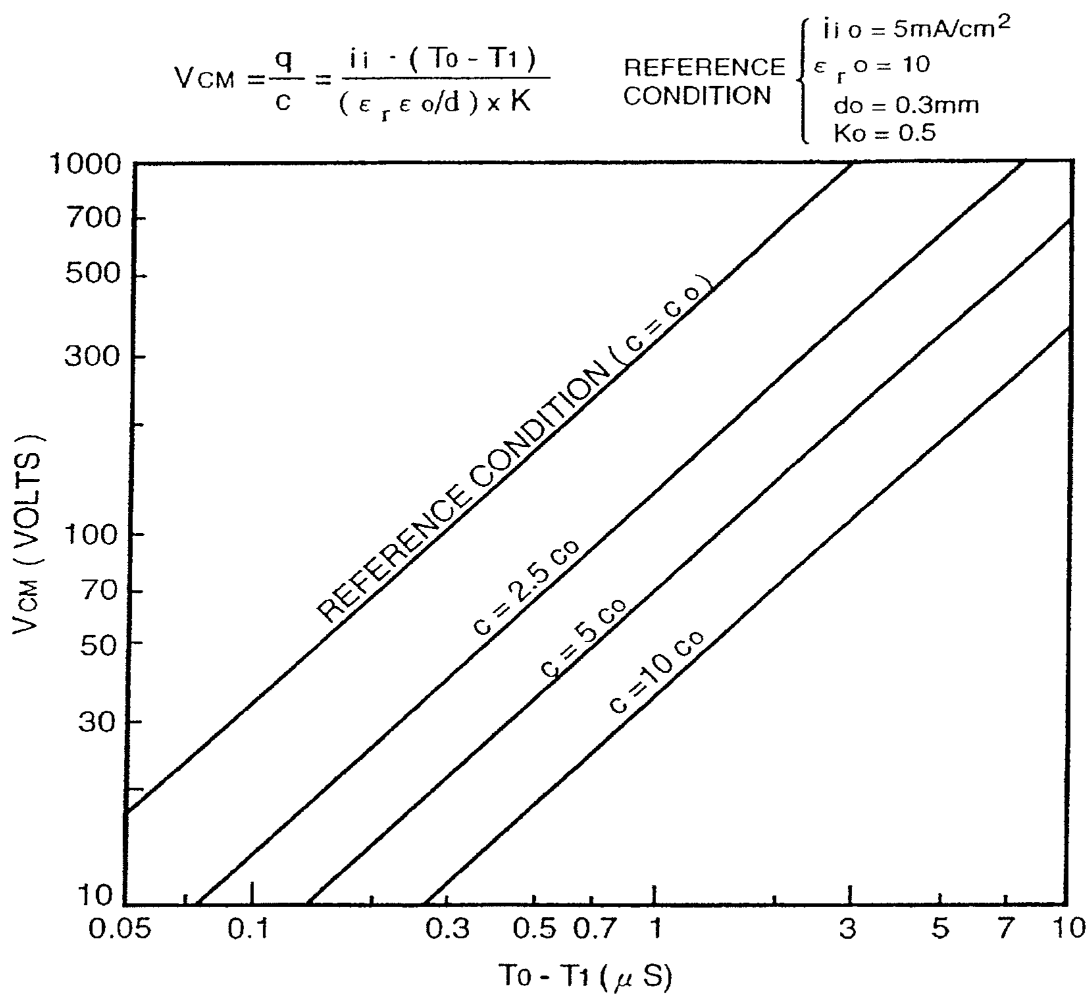

VCM = q/c = ii · (To - T1) / (ε r ε o/d) x K
REFERENCE CONDITION
ii o = 5mA/cm2
ε r o = 10
do = 0.3mm
Ko = 0.5
REFERENCE CONDITION (c = c o)
c = 2.5 co
c = 5 co
c =10 co
VCM (VOLTS)
1000
700
500
300
100
70
50
30
10
0.05
0.1
0.3
0.5
0.7
1
3
5
7
10
To - T1 (μ S)

FIG. 11

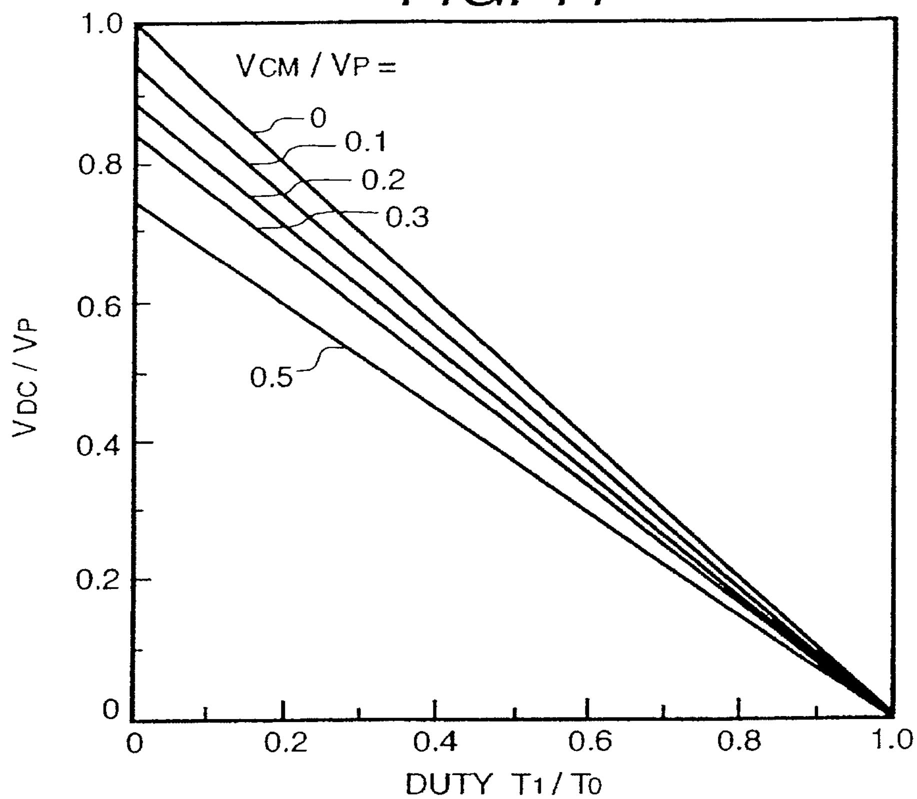

VCM / VP =
0
0.1
0.2
0.3
0.5
VDC / VP
DUTY T1 / T0
1.0
0.8
0.6
0.4
0.2
0
0.2
0.4
0.6
0.8
1.0

FIG. 12

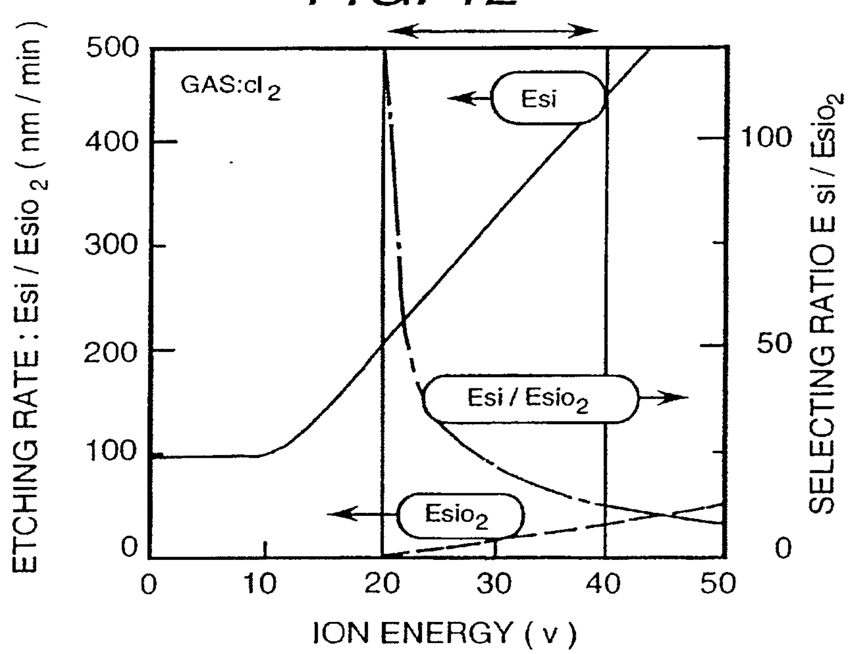

GAS:cl2
Esi
Esi / Esio2
Esio2
ETCHING RATE : Esi / Esio 2 (nm / min)
SELECTING RATIO E si / Esio2
ION ENERGY (v)
500
400
300
200
100
0
10
20
30
40
50
100
50

FIG. 13

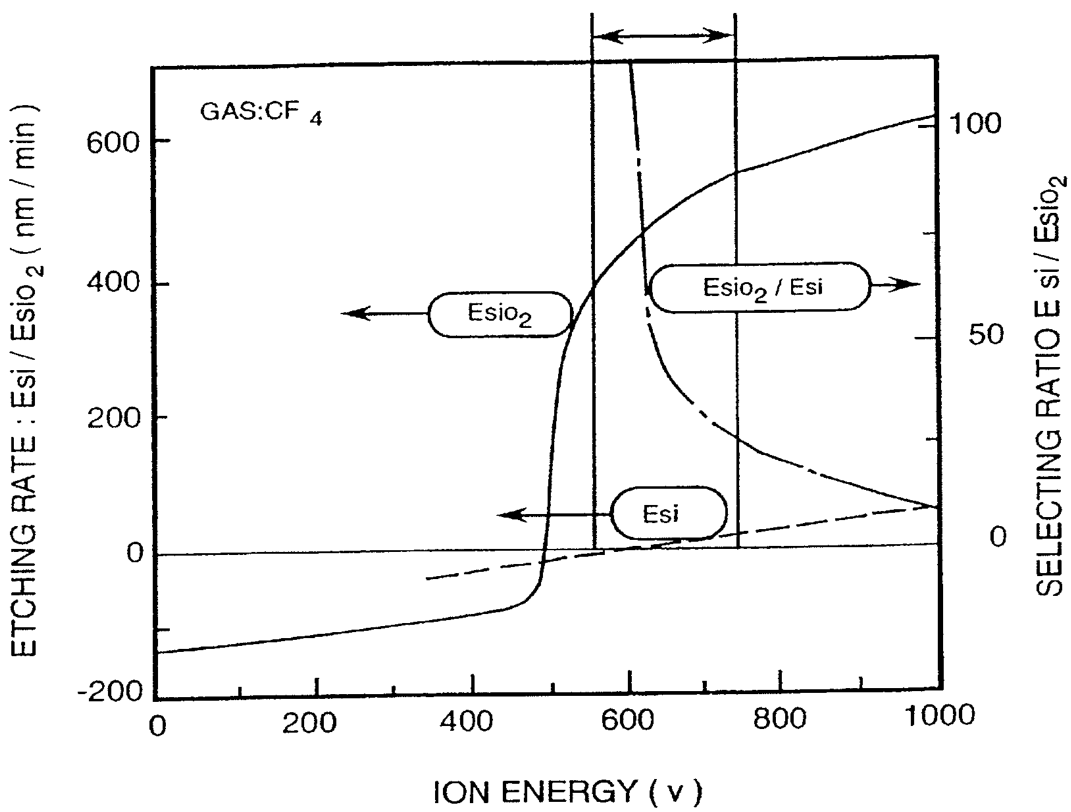

GAS:CF 4
600
400
200
0
-200
0
200
400
600
800
1000
100
50
0
ETCHING RATE : Esi / Esio2 (nm / min)
SELECTING RATIO E si / Esio2
ION ENERGY (v)
Esio2
Esio2 / Esi
Esi

FIG. 14

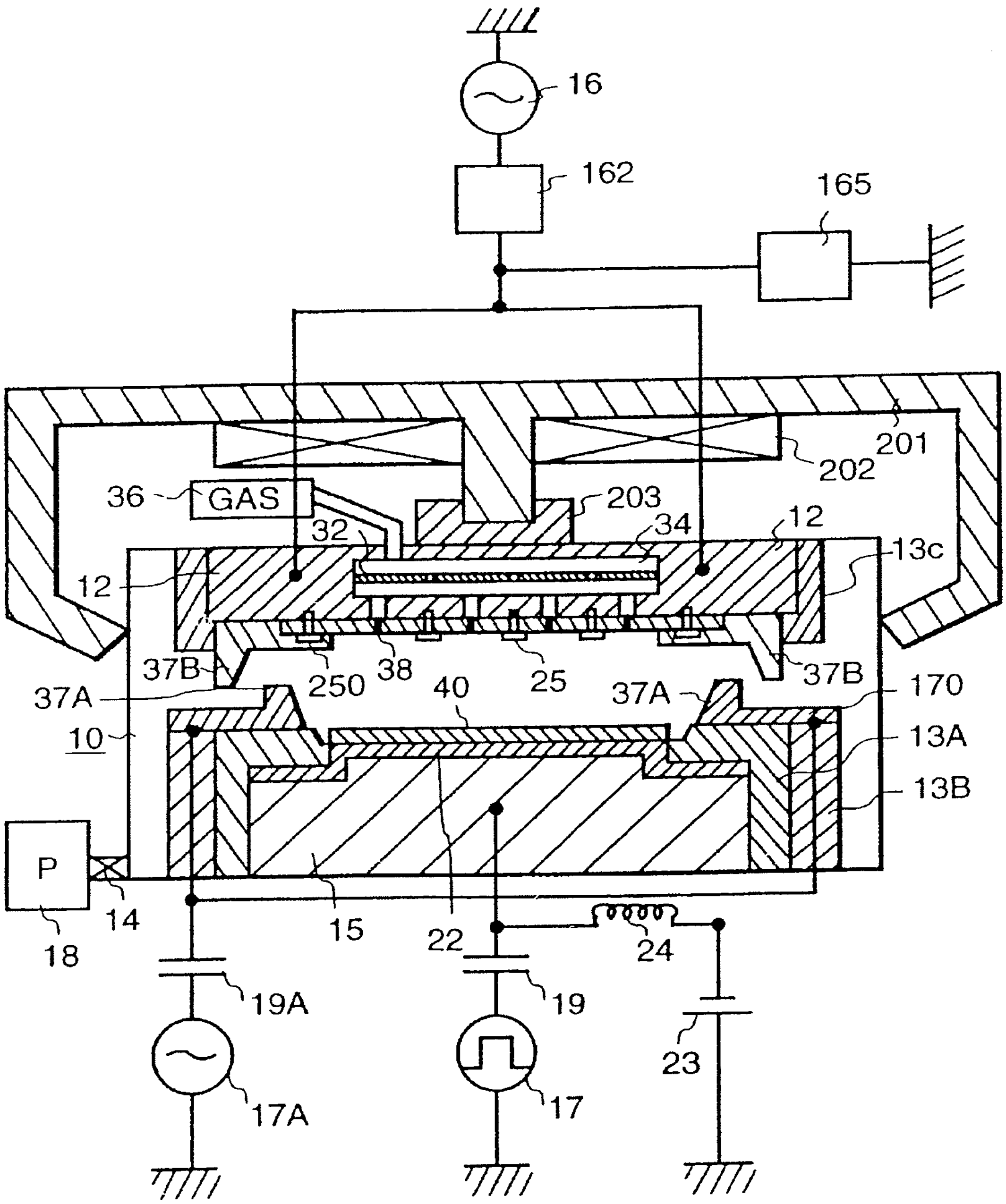

16
162
165
201
202
36
GAS
203
32
34
12
13c
12
37B
250
38
25
37B
37A
40
37A
170
10
13A
13B
P
14
18
15
22
24
19A
19
23
17A
17

FIG. 15

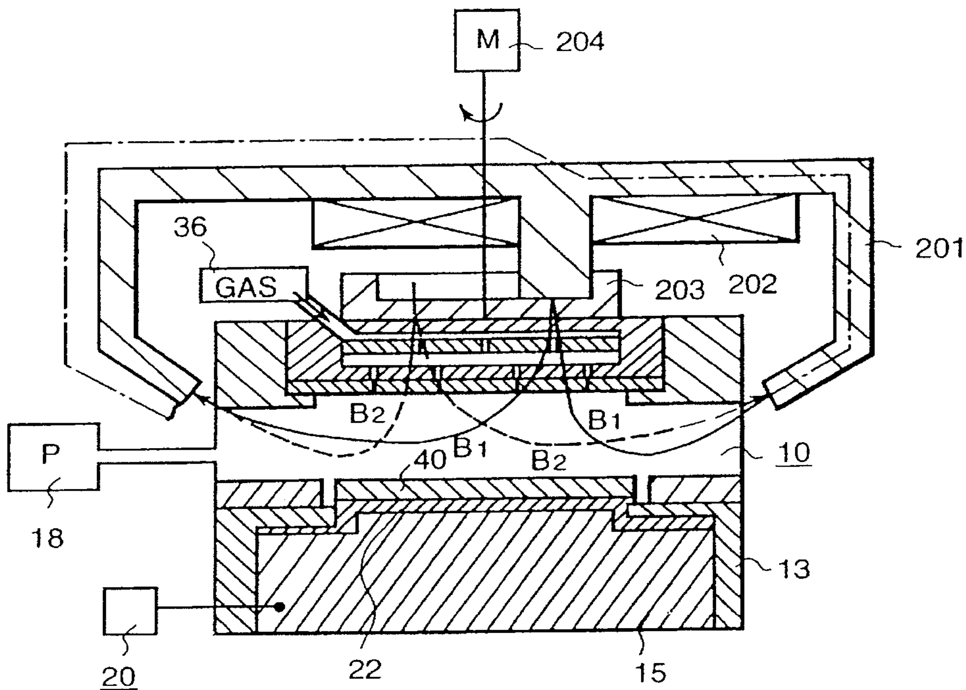

M
204
36
GAS
203
202
201
B2
B1
40
B1
B2
10
P
18
13
20
22
15

FIG. 16

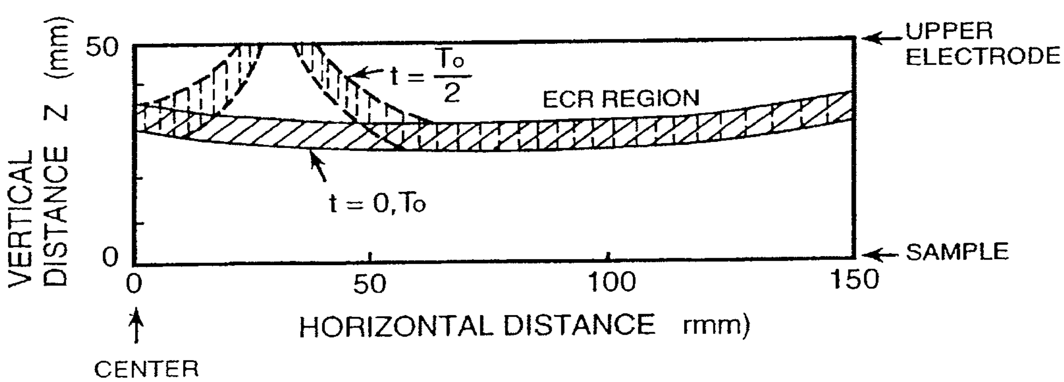
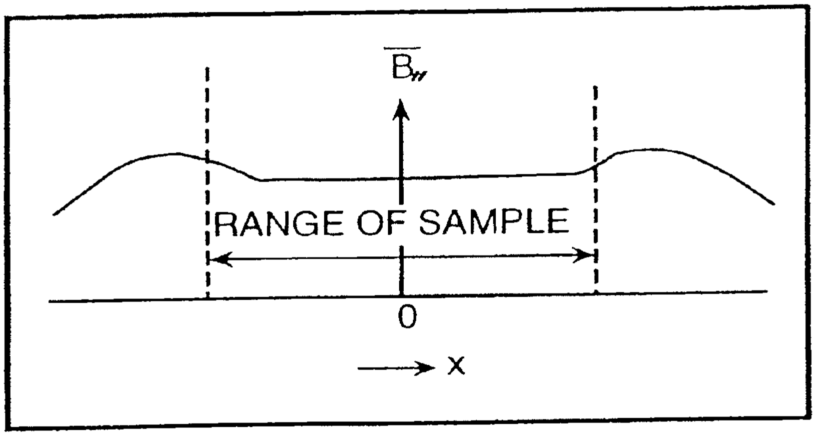
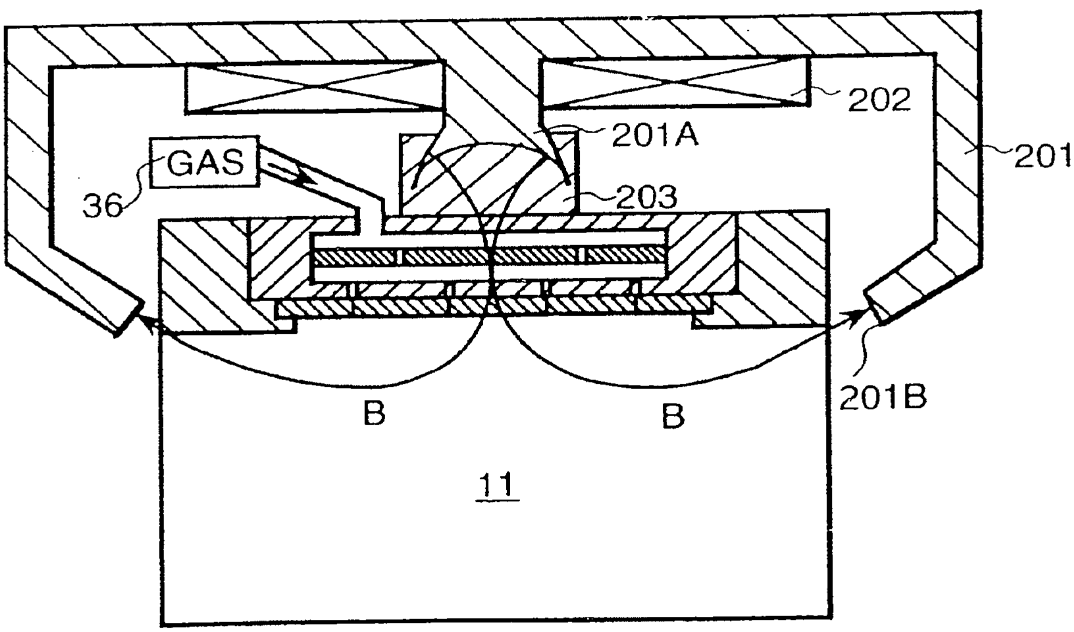

VERTICAL DISTANCE Z (mm)
50
0
UPPER ELECTRODE
SAMPLE
t = To/2
ECR REGION
t = 0,To
0
50
100
150
HORIZONTAL DISTANCE rmm)
CENTER

FIG. 17



$\overline{B}_{H}$
RANGE OF SAMPLE
0
x

FIG. 18



202
201A
201
GAS
36
203
B
B
201B
11

FIG. 19

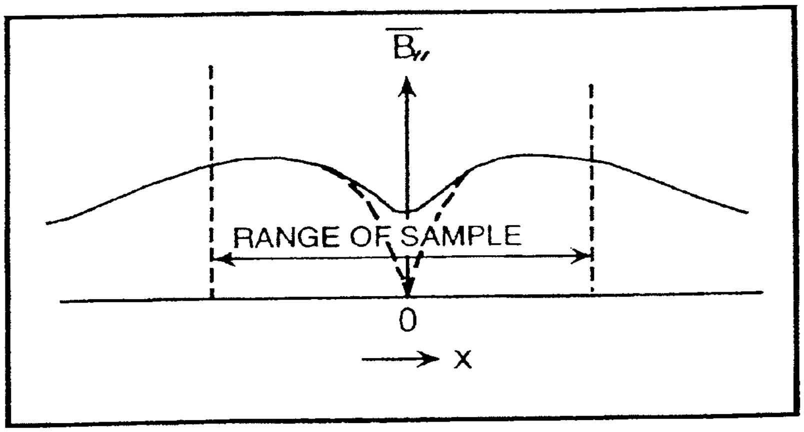

$\overline{B}_{//}$
RANGE OF SAMPLE
0
X

FIG. 20

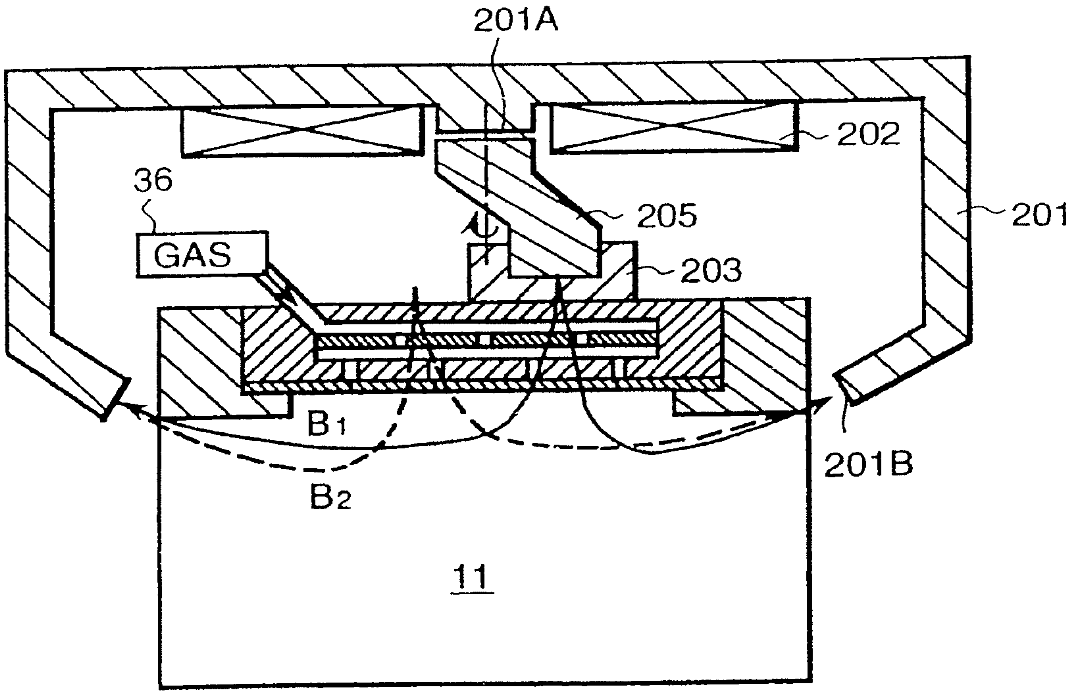

201A
202
36
205
201
GAS
203
B1
201B
B2
11

FIG. 21

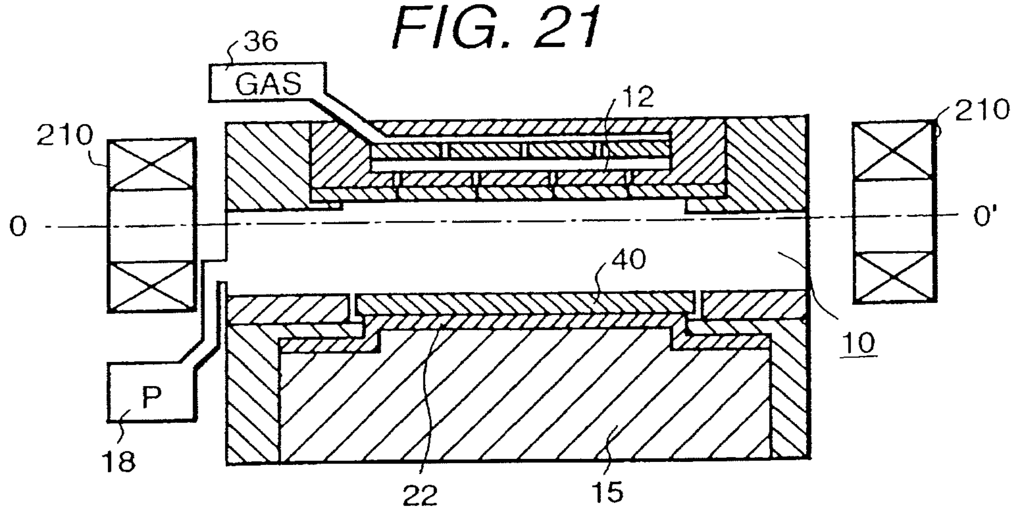

36
GAS
12
210
210
0
0'
40
10
P
18
22
15

FIG. 22

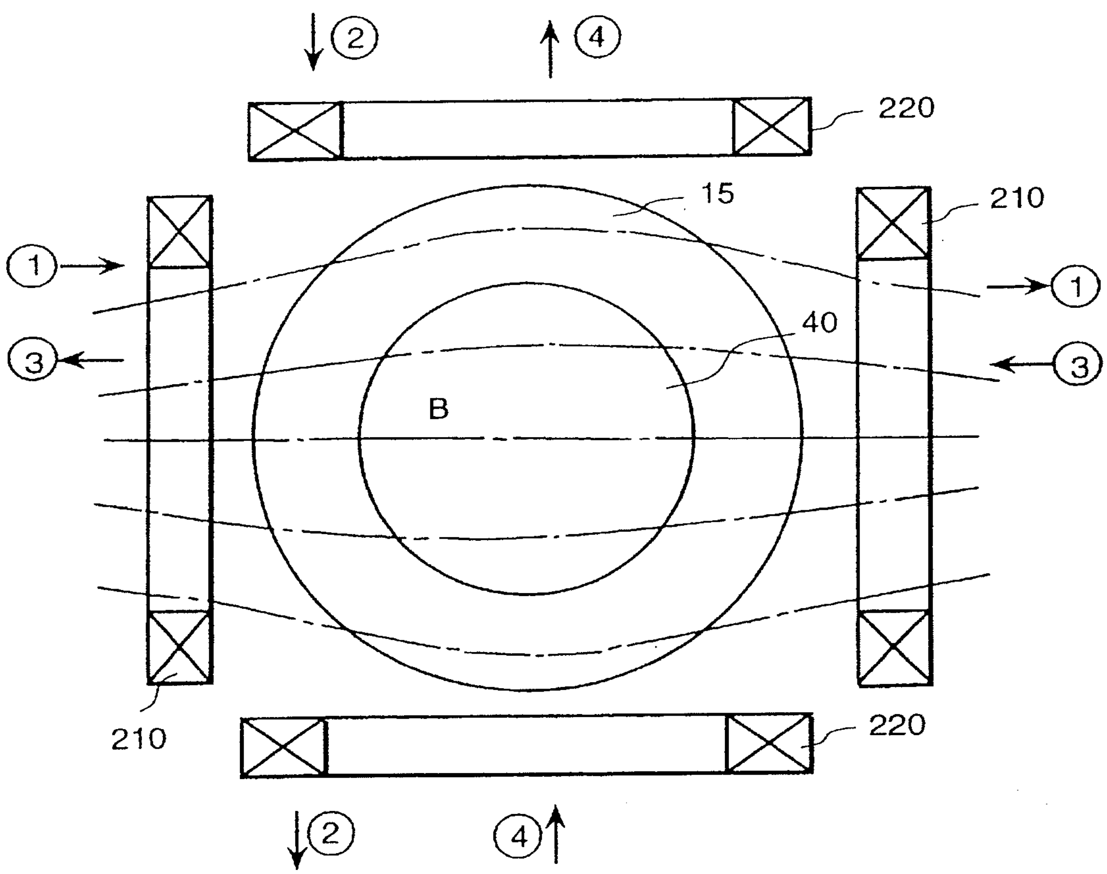

2
4
220
15
210
1
1
40
3
3
B
210
220
2
4

FIG. 23

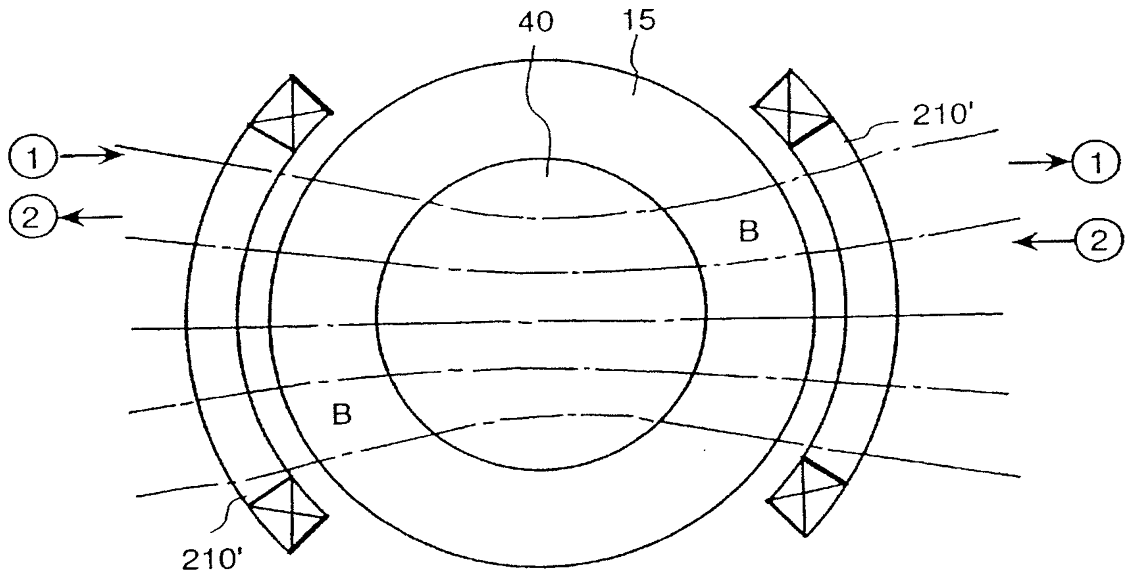


FIG. 24

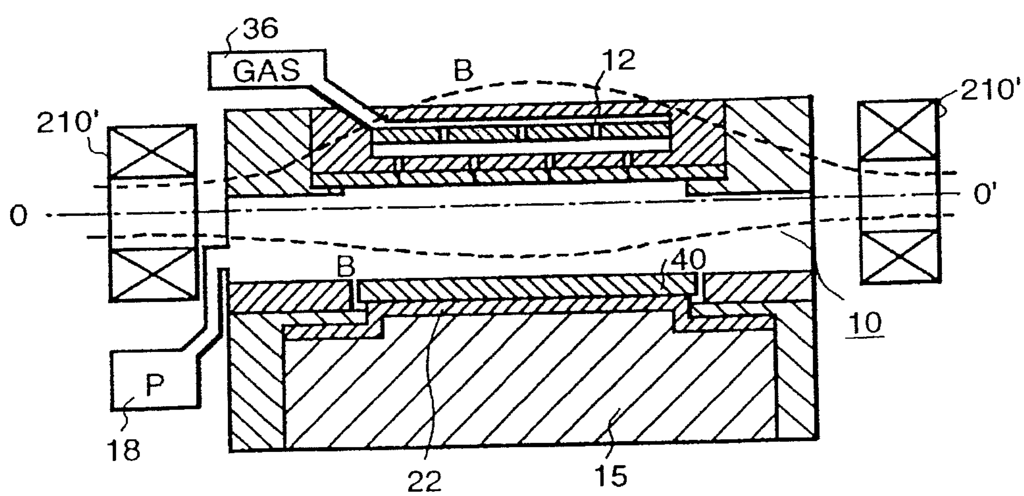


FIG. 25

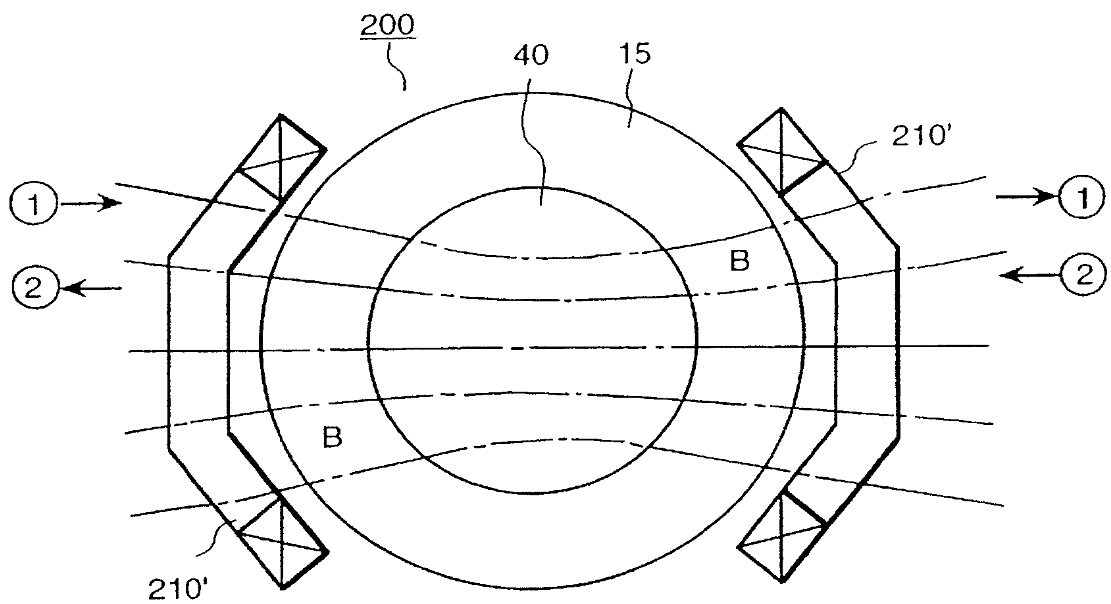


FIG. 26

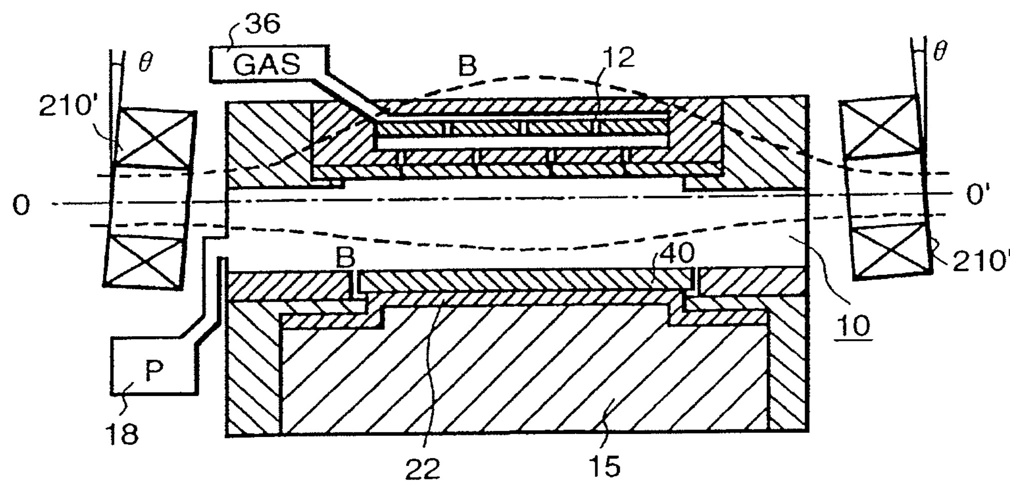


FIG. 27

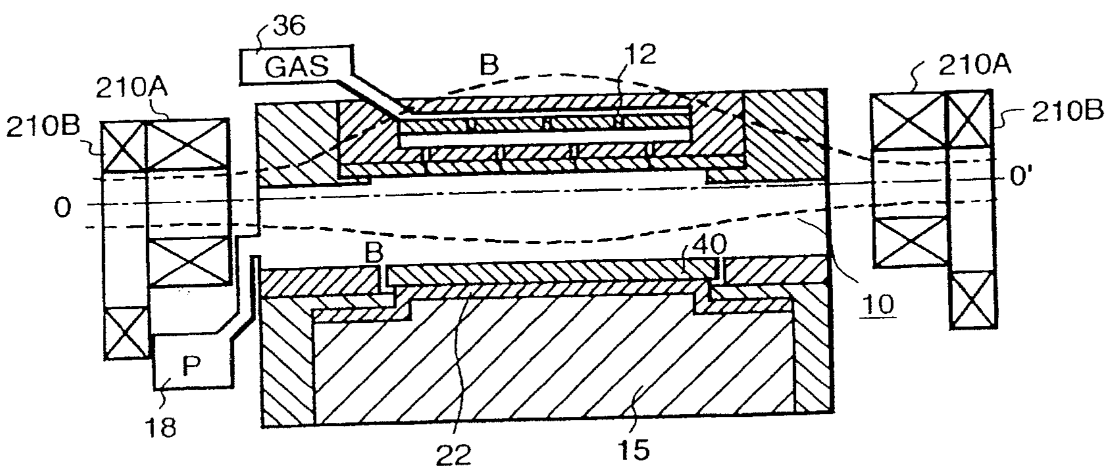
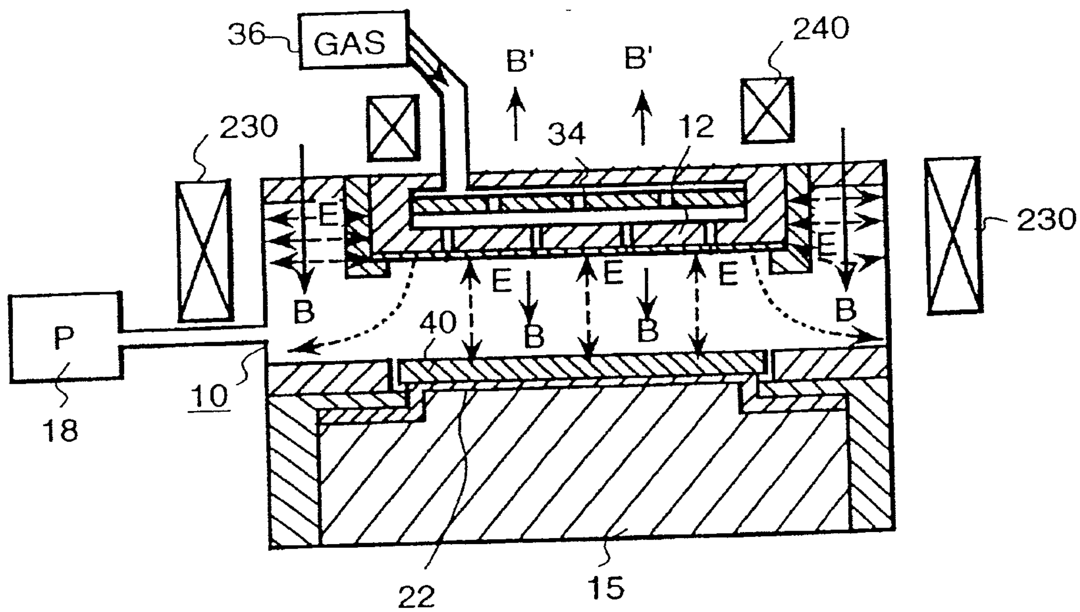
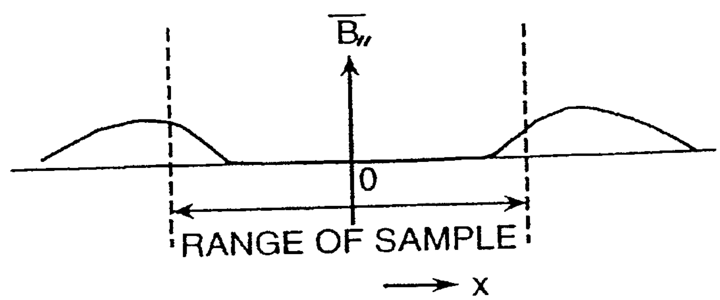


FIG. 28



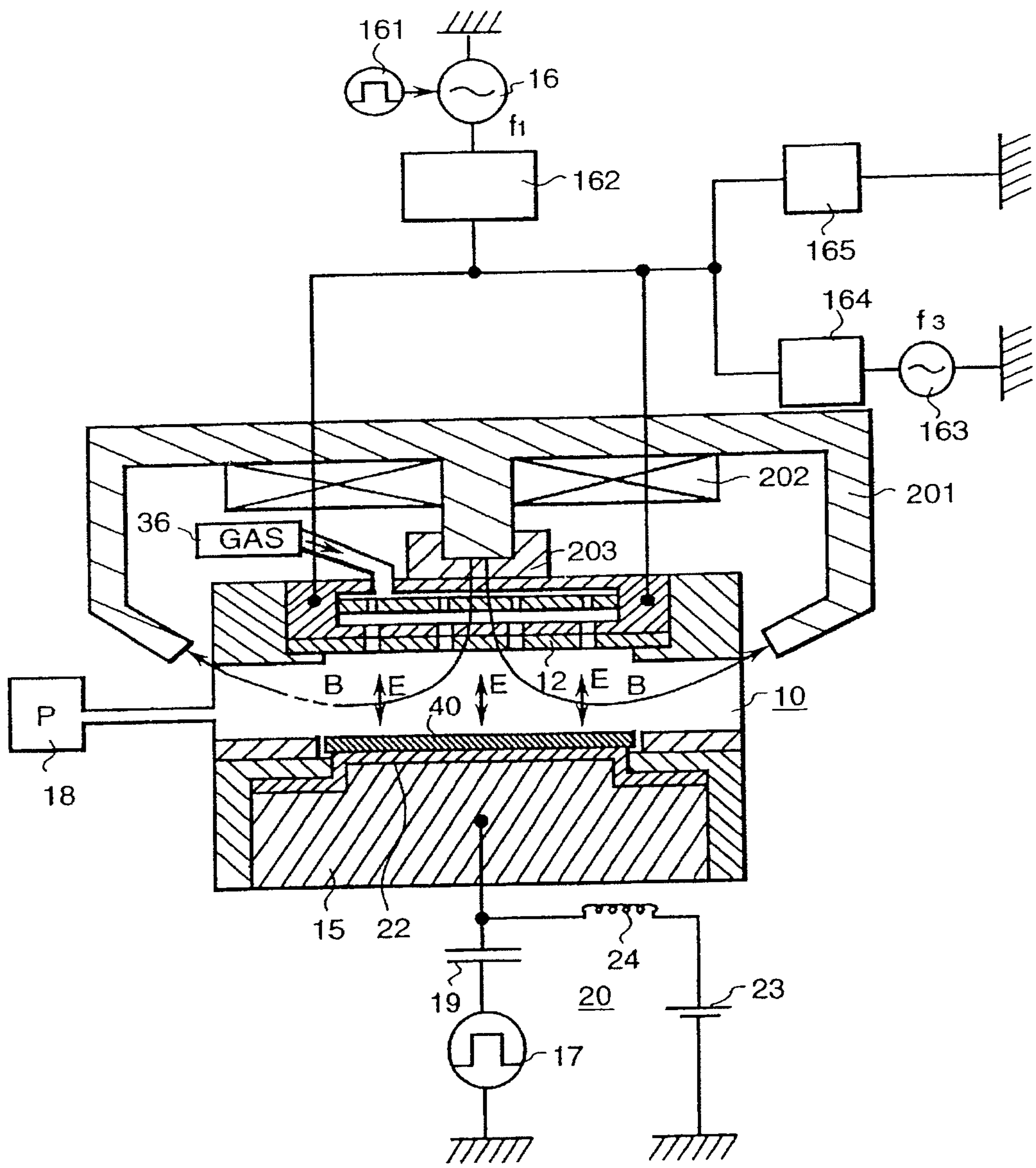
36
GAS
B'
B'
240
230
34
12
E
E
230
E
E
E
B
B
B
B
B
P
40
10
18
22
15

FIG. 29



B//
0
RANGE OF SAMPLE
x

FIG. 30



161
16
f_1
162
165
164
f_3
163
202
201
36
GAS
203
B
E
E
12
E
B
10
40
P
18
15
22
24
19
20
23
17

FIG. 31

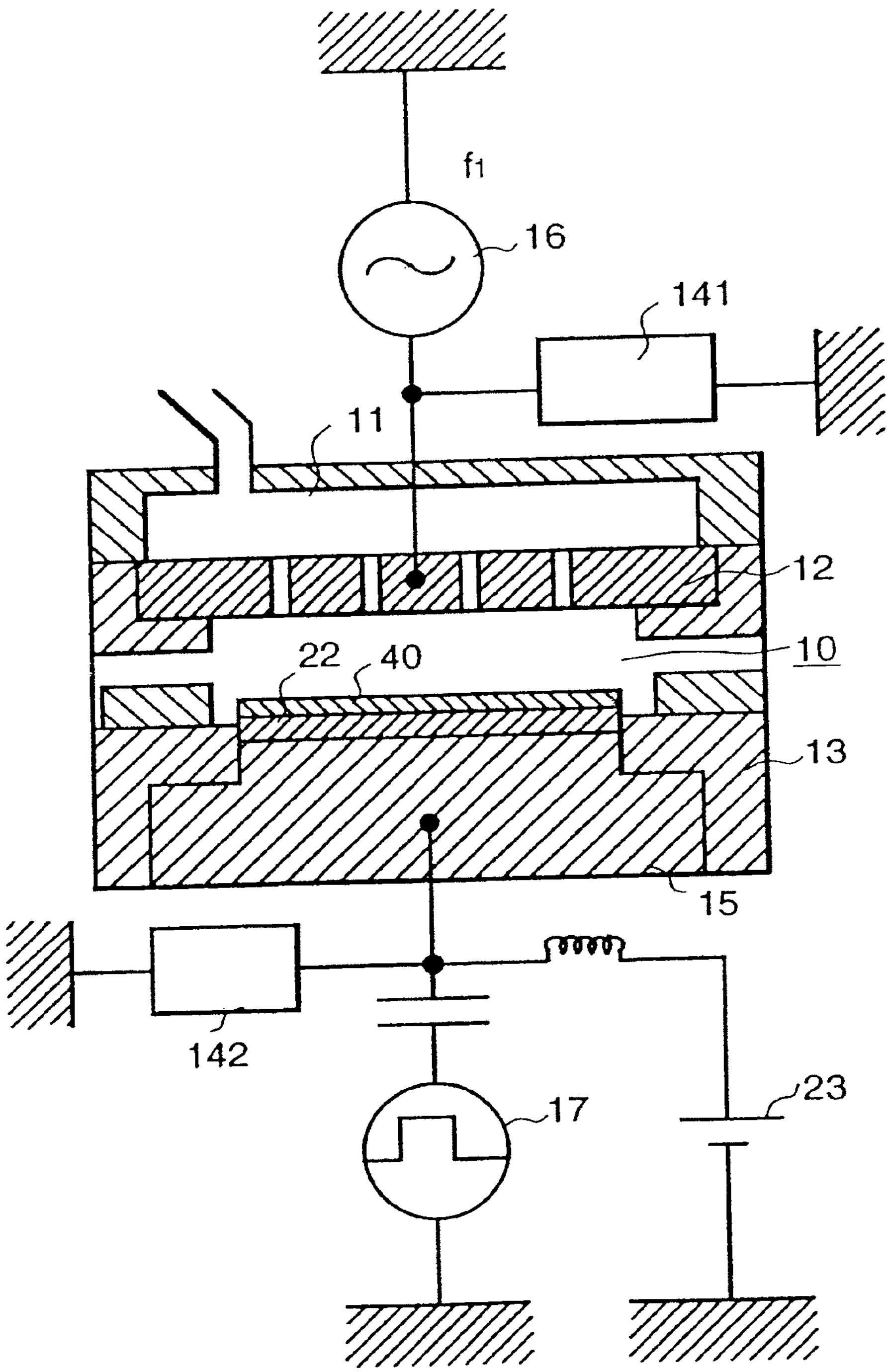
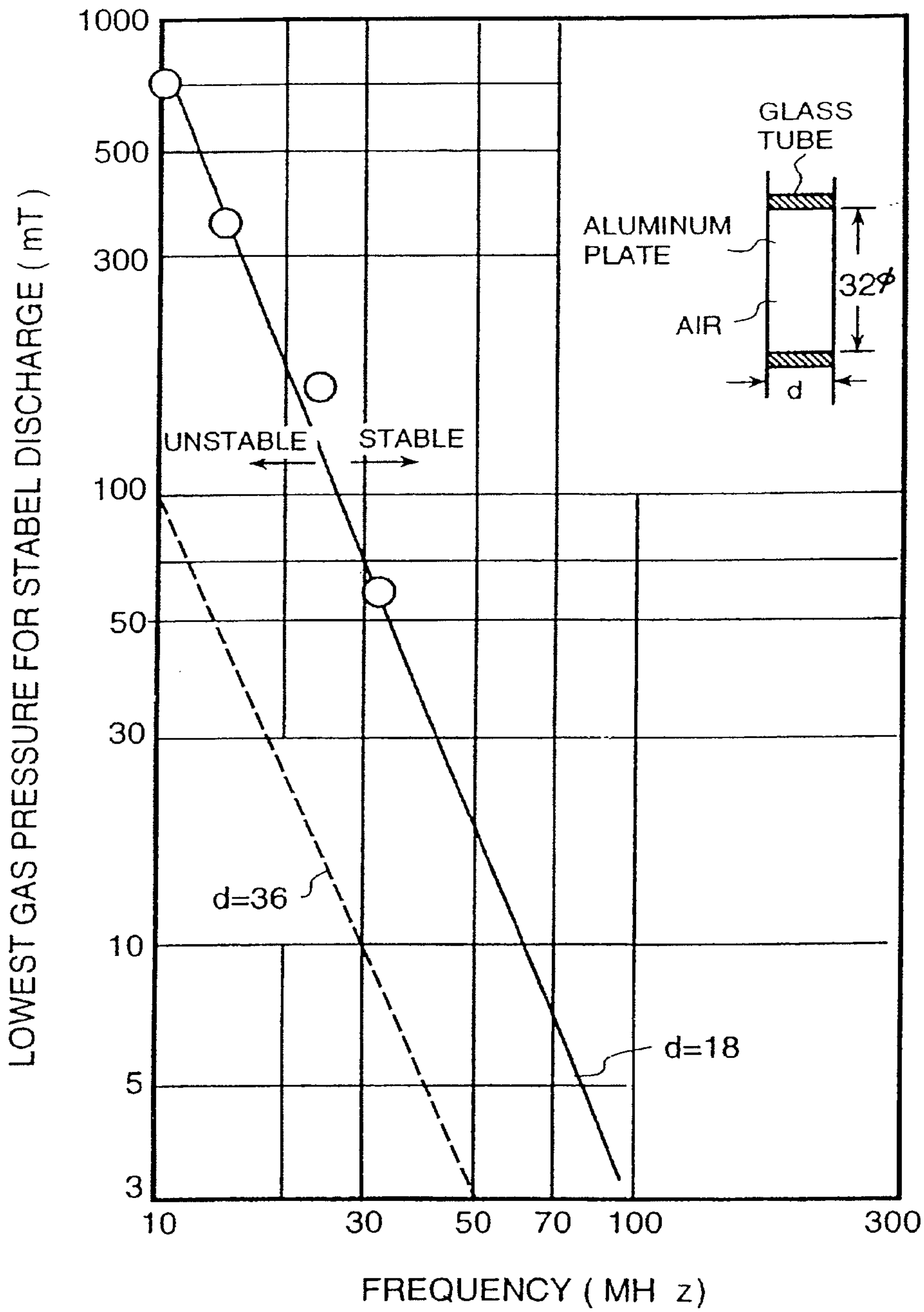


FIG. 32



FREQUENCY-LOWEST GAS PRESSURE FOR STABLE DISCHARGE CHARACTERISTC

FIG. 33

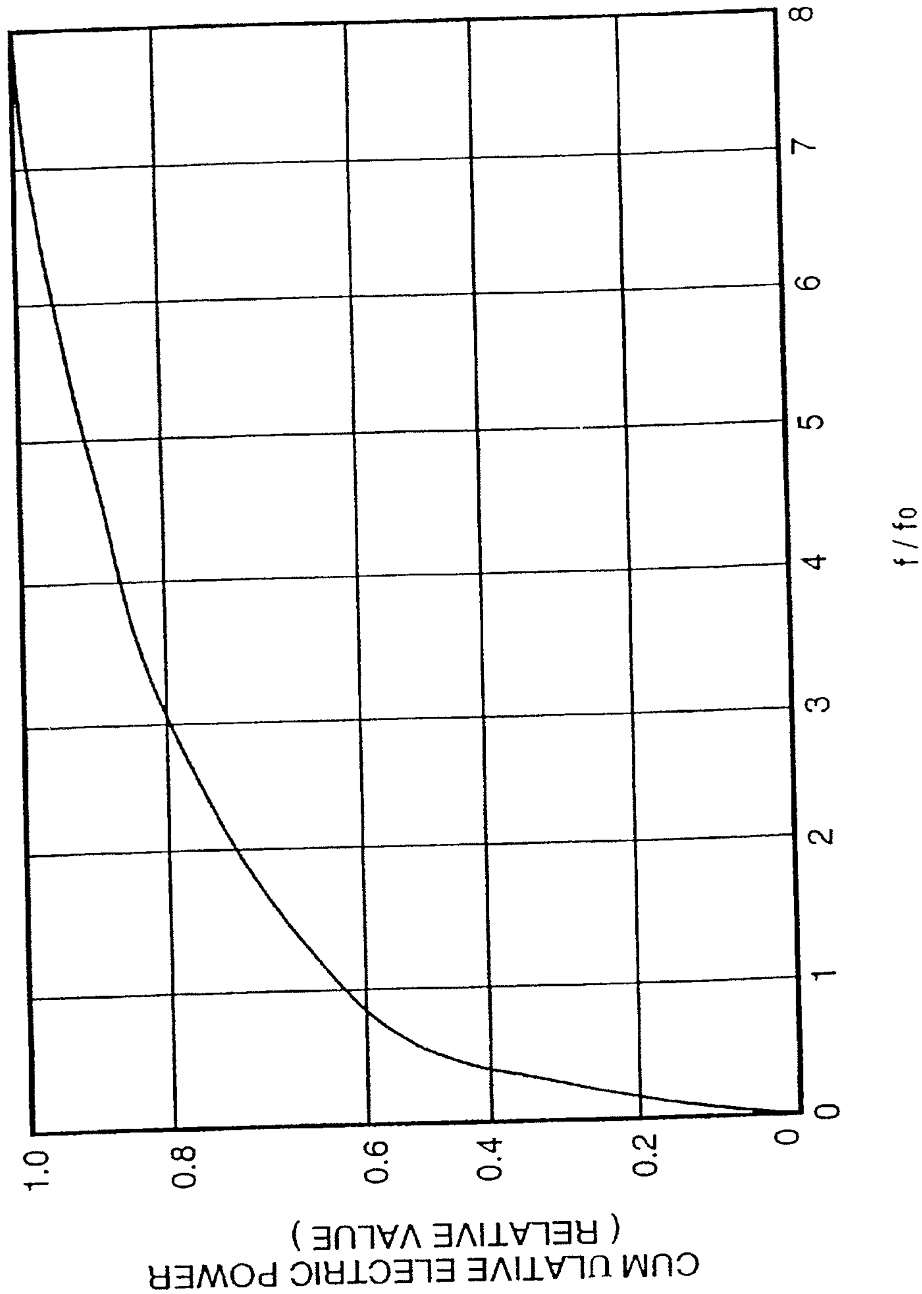

CUM ULATIVE ELECTRIC POWER
(RELATIVE VALUE)
1.0
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
f / fo

FIG. 34

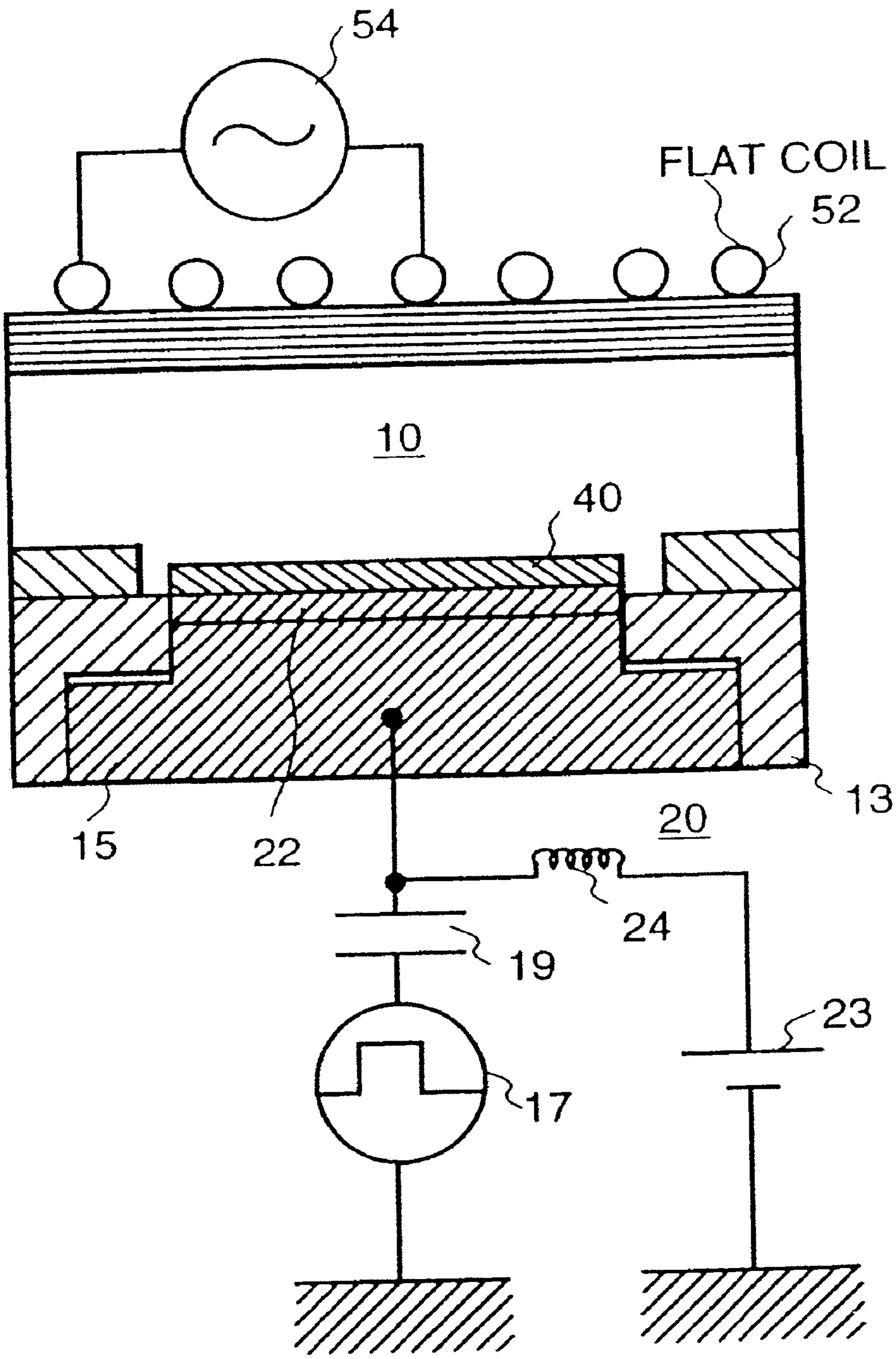


FIG. 35

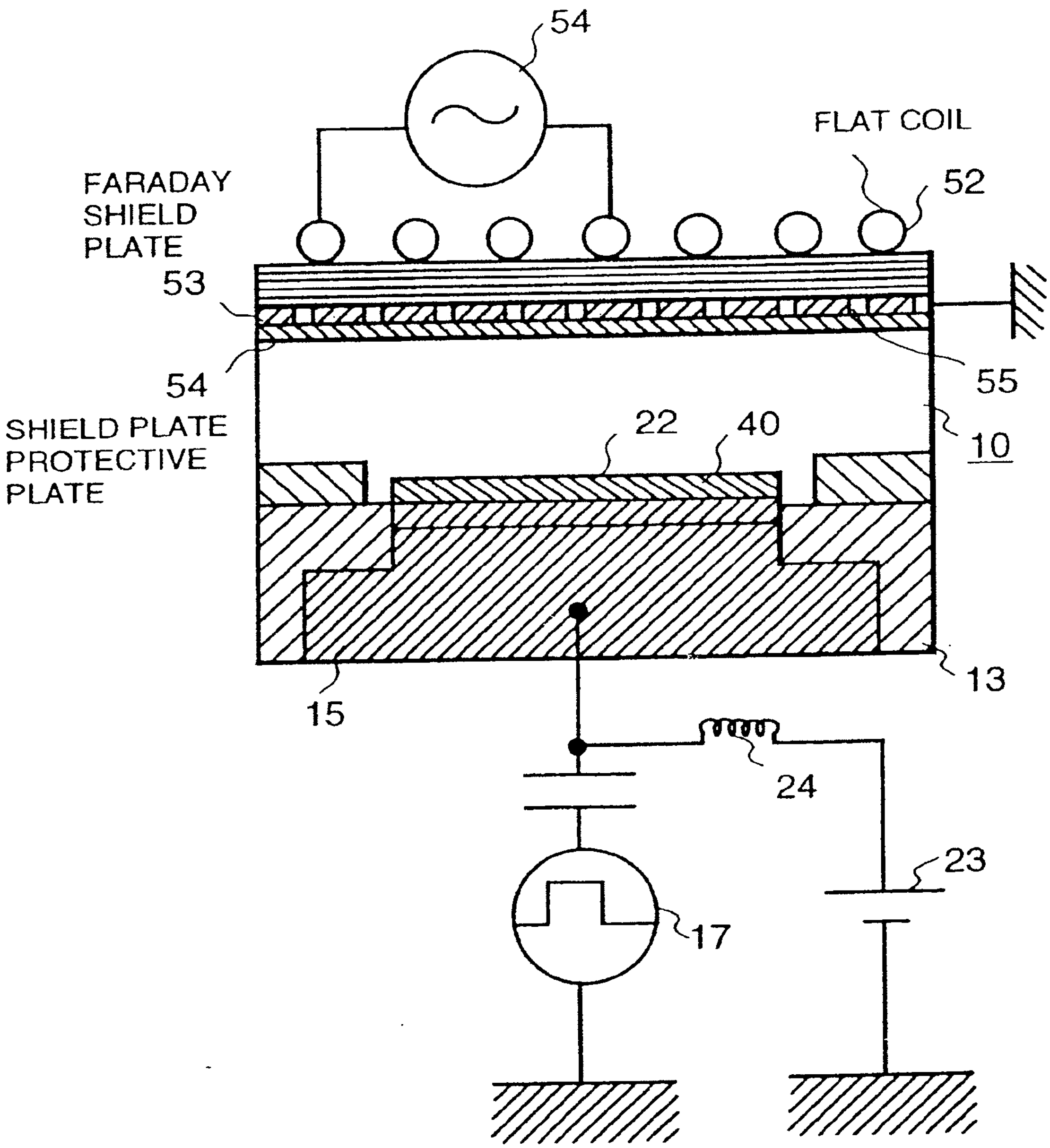

54
FLAT COIL
52
FARADAY
SHIELD
PLATE
53
54
55
SHIELD PLATE
PROTECTIVE
PLATE
22
40
10
13
15
24
23
17

FIG. 36

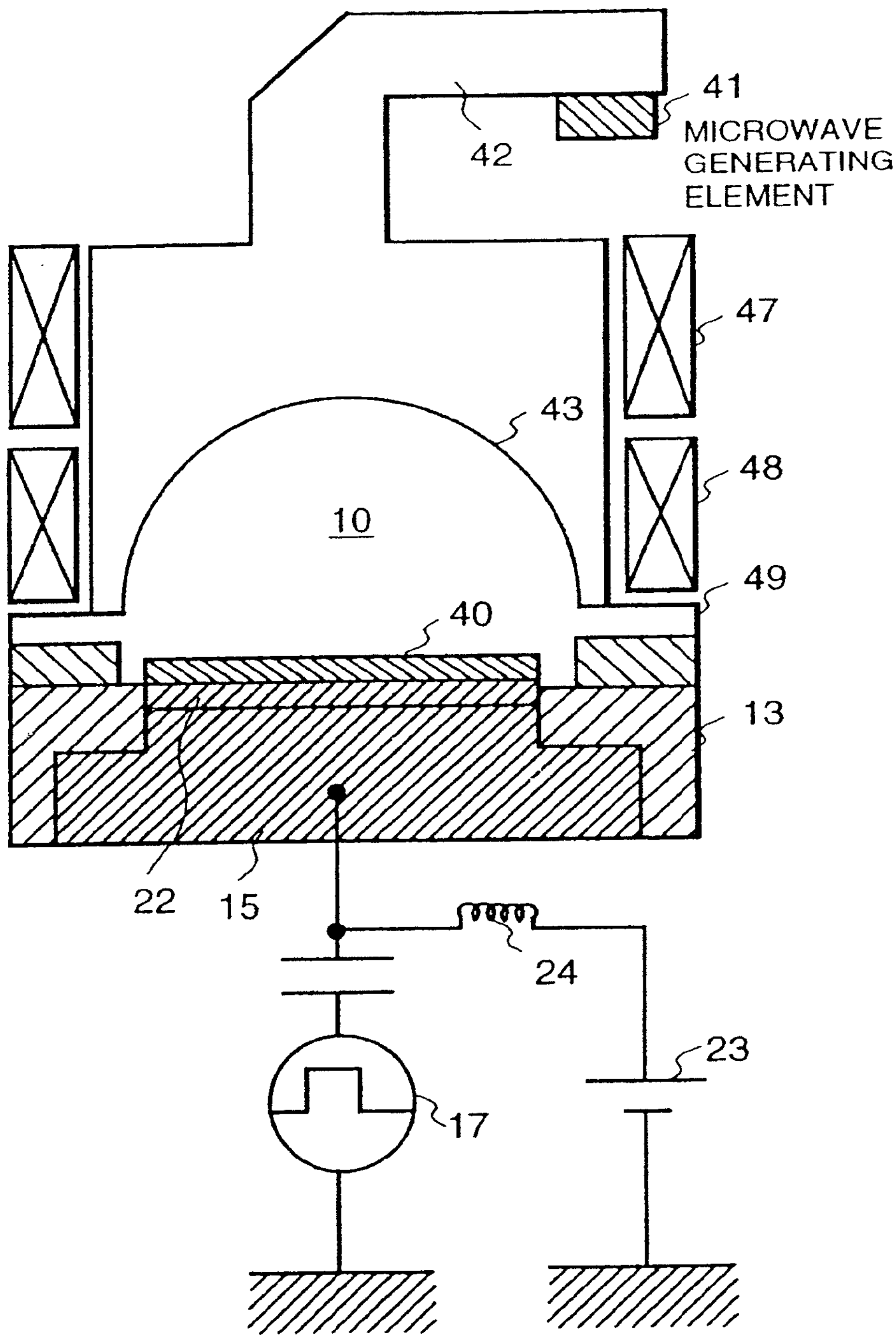

41
MICROWAVE
GENERATING
ELEMENT
42
47
43
48
10
49
40
13
22
15
24
23
17

FIG. 37

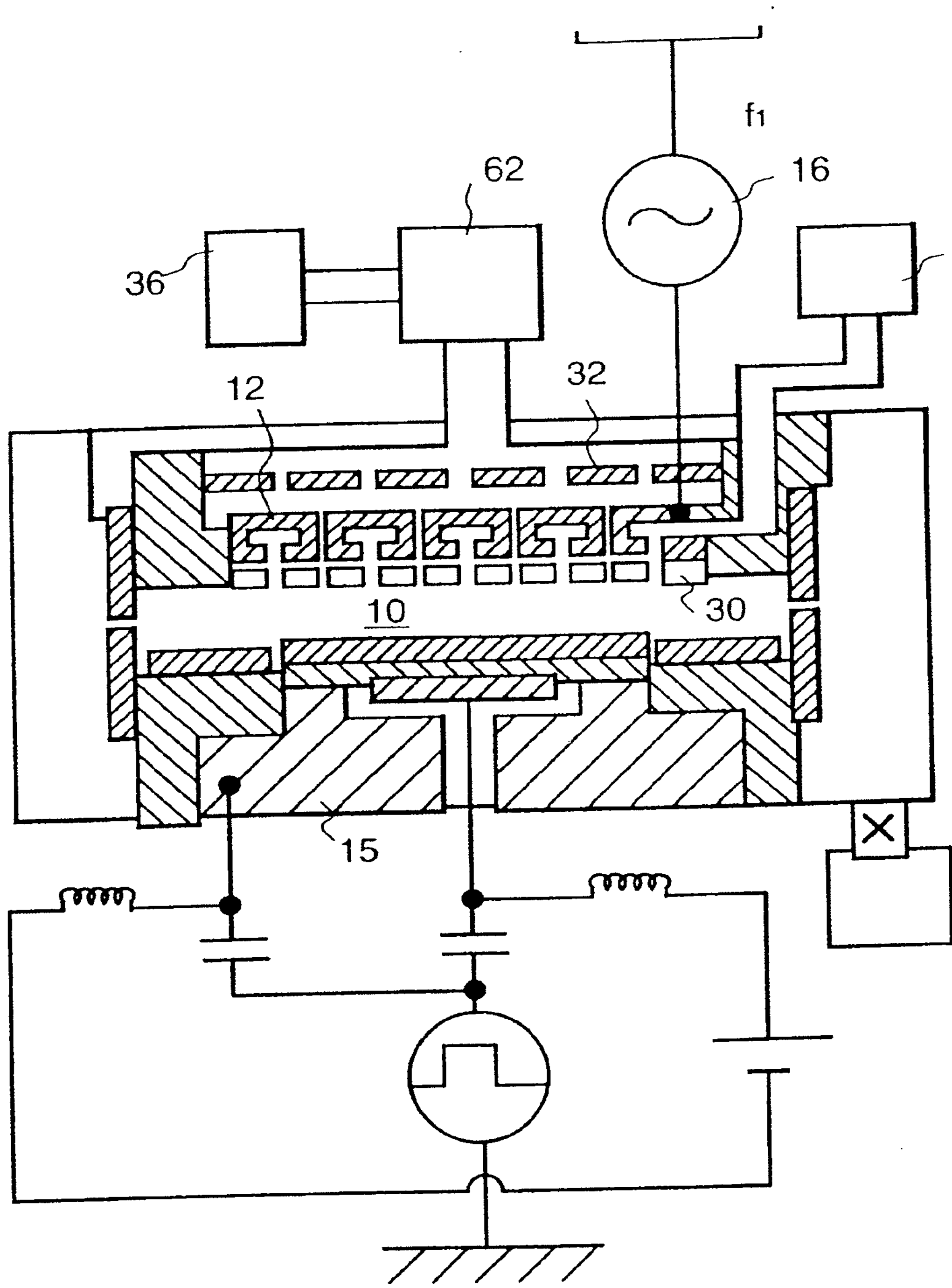


FIG. 38

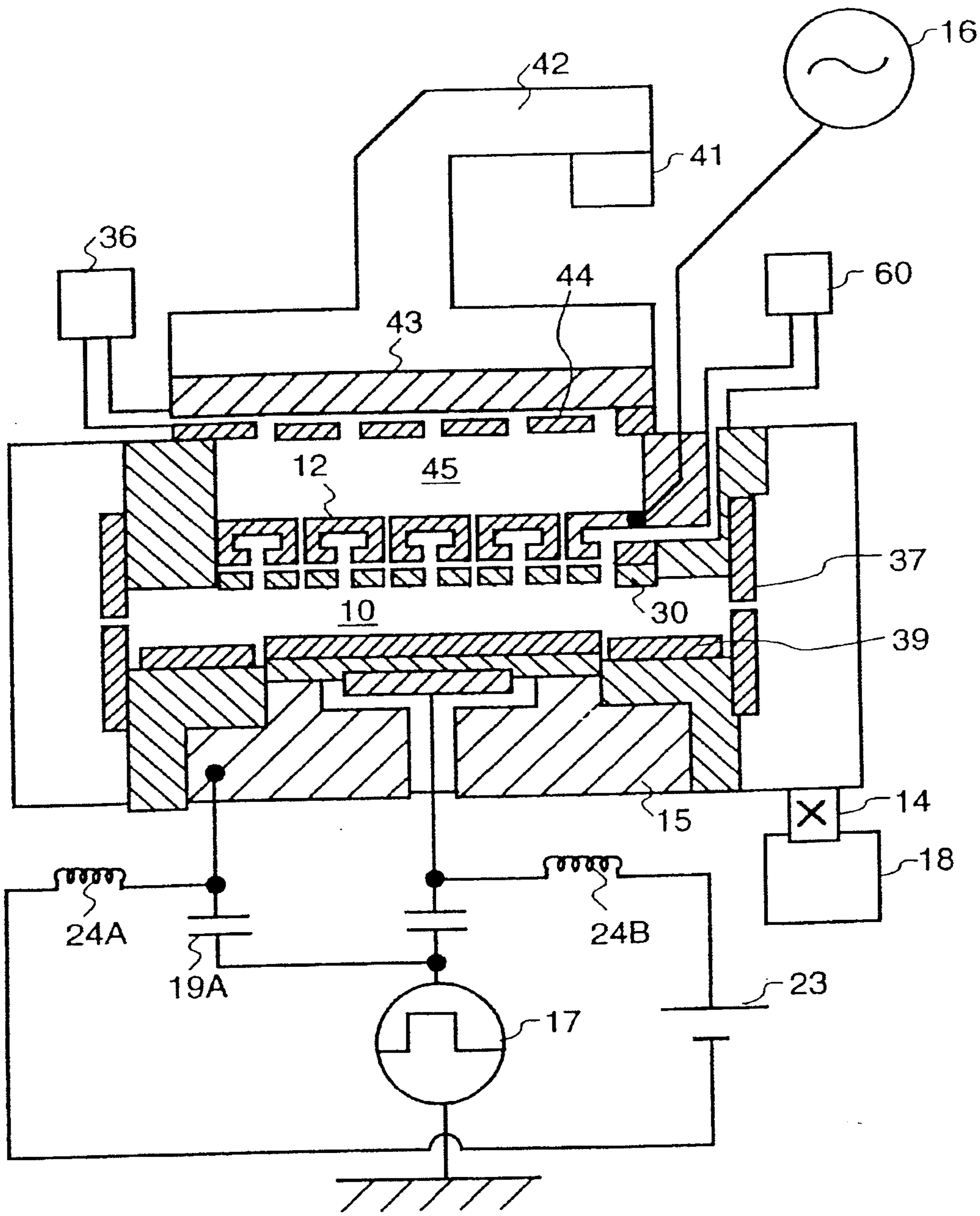


FIG. 39

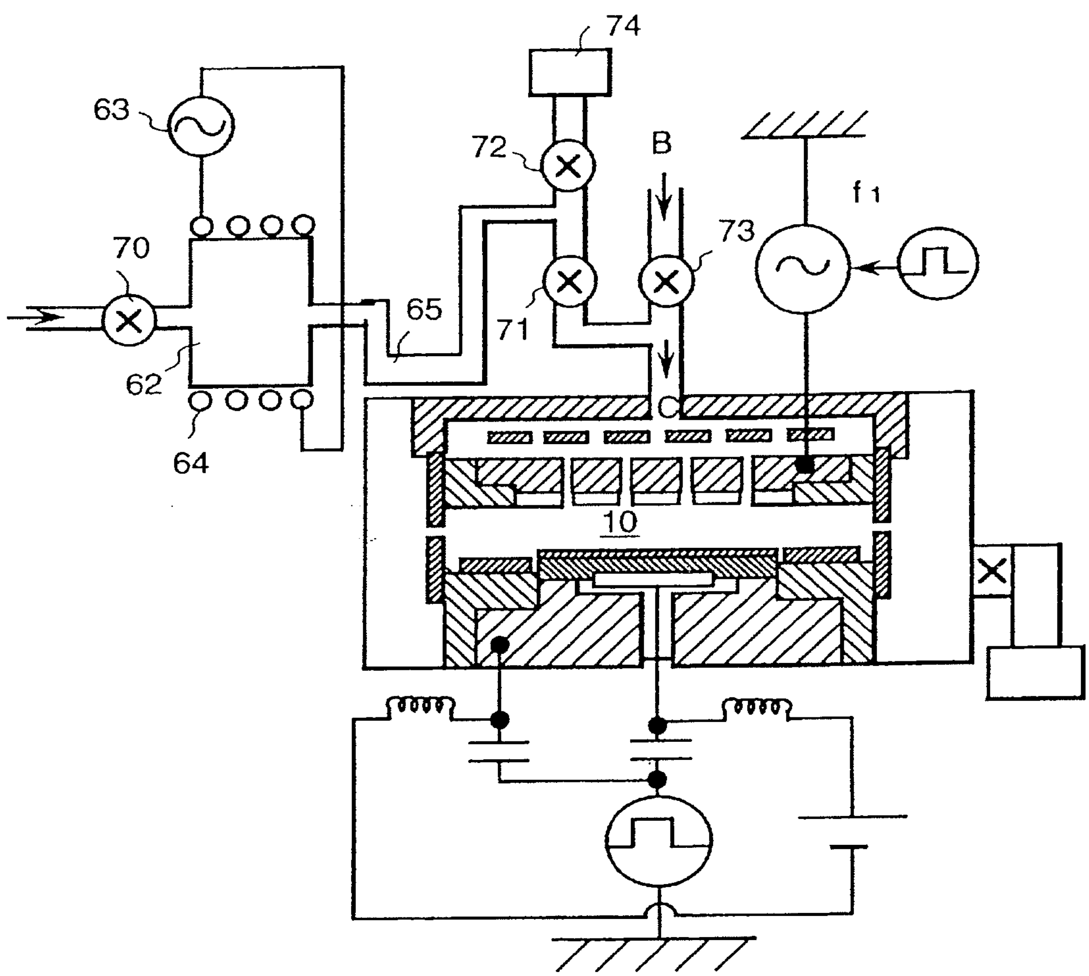
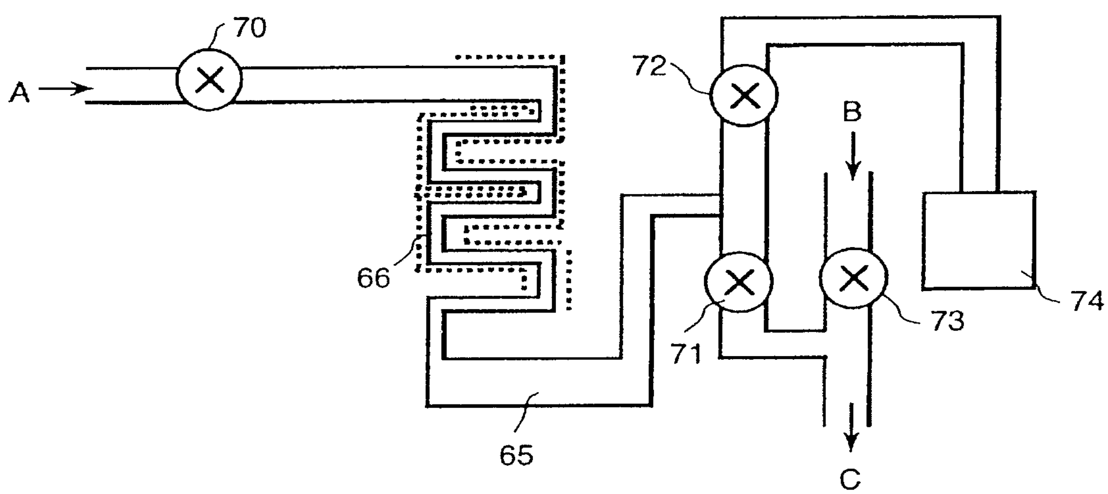


FIG. 40



PLASMA PROCESSING APPARATUS AND PLASMA PROCESSING METHOD

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of application Ser. No. 08/808,805, filed on Feb. 28, 1997, now U.S. Pat. No. 6,129,806, the entire disclosure of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

The present invention relates to a plasma processing apparatus and a plasma processing method, and more particularly relates to a plasma processing apparatus and a plasma processing method suitable for forming a fine pattern in a semiconductor device manufacturing process.

The need for improving the fine pattern manufacturing capability and the processing speed in plasma processing is growing further as integration of semiconductor devices become higher. In order to respond to this need, it is required to decrease the pressure of the processing gas and to increase the plasma density.

In regard to plasma processing apparatuses aiming to decrease the pressure of the processing gas and to increase the plasma density, there presently are: (1) a method which utilizes the electron cyclotron resonance phenomena (hereinafter referred to as ECR) of a microwave (e.g., 2.45 GHz electromagnetic field with a static magnetic field (e.g., 875 G); and (2) a method which utilizes induction coupling processing (hereinafter referred to as ICP) in which a plasma is generated by generating an induced electromagnetic field by exciting a coil using an RF frequency power source.

In a case where a film of the oxide film group is etched using a gas of fluorocarbons, when either of the methods of the ECR described in the above item (1) or the ICP described in the item (2) is employed, it is difficult to increase selectivity of an oxide-film to a base material, for example, Si or SiN since dissociation of the gas progresses excessively.

On the other hand, in a conventional method of generating a plasma by applying an RF frequency voltage between a pair of parallel flat plates, it is difficult to stably discharge under a pressure condition below 10 Pa.

As a countermeasure, there are: (3) a two-frequency exciting method in which a plasma is generated using a high frequency voltage above several tens MHz and bias control of a sample is performed using a low frequency voltage below several MHz, which is disclosed in Japanese Patent Application Laid-Open No. 7-297175 or Japanese Patent Application Laid-Open No. 3-204925; and (4) a magnetron RIE (hereinafter referred to as M-RIE) method which utilizes an action of confining electrons by Lorentz force of electrons by applying a magnetic field B in a direction intersection with a self-bias electron field (E) induced on the surface of the sample, which is disclosed in Japanese Patent Application Laid-Open No. 2-312231.

Further, a method of increasing plasma density under a low pressure condition is described in Japanese Patent Application Laid-Open No. 56-13480. This method obtains a high plasma density under a low pressure condition of 0.1 Pa to 1 Pa by utilizing an electron cyclotron resonance (ECR) effect induced by a microwave of electromagnetic waves (e.g., 2.45 GHz) and a static magnetic field (e.g., 875 gauss).

On the other hand, in the technical field of performing etching processing or film forming processing of a semi-

conductor material using a plasma, an apparatus is employed having a high frequency power source for accelerating ions in a plasma to a sample table for mounting an object to be processed (for example, a semiconductor wafer substrate, hereinafter referred to as the sample) and an electrostatic attracting film for holding the sample on the sample table by an electrostatic attracting force.

For example, in an apparatus disclosed in the specification of U.S. Pat. No. 5,320,982, a plasma is generated by microwaves and a sample is held on a sample table by an electrostatic force, and using a high frequency power source output having a sinusoidal waveform as a bias electric source, the ion energy incident on the sample is controlled by connecting the power source to the sample table while the temperature of the sample is being controlled by introducing a heat transfer gas between the sample and the sample table.

Further, Japanese Patent Application Laid-Open No. 62 280378 discloses that a distribution of the ion energy incident to the sample can be narrowed by applying a pulse-shaped ion control bias voltage to a sample table for maintaining the electric field intensity between a plasma and an electrode at a constant value. Thereby, it is possible to improve the dimensional accuracy of plasma etching processing and the etching rate ratio of a processed film to a base material by several times.

Furthermore, Japanese Patent Application Laid-Open No. 6-61182 discloses that it is possible to prevent the occurrence of notches by generating a plasma utilizing electron cyclotron resonance and applying a pulse bias having a width of pulse duty of 0.1% or more to a sample.

An example of increasing a plasma density by generating cyclotron resonance using an electromagnetic wave of VHF band and a static magnetic field is described in the Journal of Applied Physics, Japan, Vol. 28, No. 10. However, in this example, by applying a high frequency voltage of 144 MHz to a coaxial central conductor and adding a magnetic field of 51 gauss in parallel to the central conductor, cyclotron resonance is formed to generate a high density plasma, and a grounded sample table is arranged in a position downstream of the plasma generating portion.

In the plasma generating methods described in Japanese Patent Application Laid-Open No. 7-288195 or Japanese Patent Application Laid-Open No. 7-297175 among the above-mentioned conventional technologies, a plasma is generated by a high frequency source of 13.56 MHz or several tens MHz. It is possible to generate a plasma appropriate for etching an oxide film under a gas pressure of several tens Pa to 5 Pa (Pascal). However, as a pattern dimension becomes as small as nearly 0.2 μm or smaller, verticality in a processed shape is strongly required and consequently it is inevitable that the gas pressure decreases.

However, in the two-frequency exciting method or the M-RIE method described above, it is difficult to stably produce a plasma having a desired density higher than nearly 5×10^{10} cm^{-3} under a pressure condition lower than 4 Pa (0.4 to 4 Pa). For example, in the two-frequency exciting method described above, even if the plasma exciting frequency is increased up to a frequency around 50 MHz, the plasma density cannot be increased but, on the contrary, it decreases. Therefore, it is difficult to produce a plasma having a desired density higher than nearly 5×10^{-10} cm^{-3} under a pressure condition of 0.4 to 4 Pa.

Further, in the M-RIE method, the density distribution of a plasma generated by an action of confining electrons by Lorentz force of electrons produced on a surface of a sample must be uniform all over the surface of the sample. However,

there is a disadvantage in that an inclination of the plasma density generally occurs over the surface of the sample due to drift of E×B. The inclination of the plasma density formed by the action of confining electrons cannot be corrected by any method such as diffusion or the like since the inclination occurs near the sheath in the vicinity of the sample where intensity of the magnetic field is strong.

Japanese Patent Application Laid-Open No. 7-288195 discloses a method of solving this problem in which it is possible to obtain a uniform plasma without inclination by arranging magnets so that the magnetic field intensity is weakened in a direction of electron drift due to the drift of E×B. even when a magnetic field with a maximum value as high as 200 gauss is applied in parallel to a sample. However, there is a disadvantage with this method in that it is difficult to follow a change in a processing condition since a condition for maintaining the plasma uniform is limited to a specified narrow range once the distribution of magnetic field intensity is fixed. In particular, in a case of a large sized sample having a diameter larger than 300 mm, when a distance between the electrodes is as narrow as 20 mm or less, pressure above the central portion of the sample becomes 10% or more greater than pressure above the peripheral portion of the sample. In order to avoid this pressure difference, the gap between the sample table and the opposite electrode must be set to 30 mm or more since, otherwise, the difficulty is likely to be increased.

As described above, in the two-frequency exciting method and the M-RIE method, it is difficult to obtain a uniform plasma density of 5×10^{10} cm^{-3} over the surface of a sample having a diameter of 300 mm or more under a pressure condition as low as 0.4 to 4 Pa. Therefore, in the two-frequency exciting method and the M-RIE method, it is difficult to manufacture the fine pattern of 0.2 μm or smaller on a wafer having a diameter larger than 300 mm uniformly and quickly with a high selectivity of the etching material to the base material.

On the other hand, a method for substantially increasing a plasma density under a low pressure condition is disclosed in Japanese Patent Application Laid-Open No. 56-13480 among the prior art described above. However, this method has a disadvantage in that in a case where a silicon oxide film or a silicon nitride film is etched using a gas containing fluorine and carbon, it is difficult to attain a desired selectivity to the base material such as Si or the like since dissociation of the gas progresses excessively and a large amount of fluorine atoms and/or molecules and/or fluorine ions are generated. The ICP method using an electromagnetic field induced by an RF power source also has a disadvantage in that dissociation of the gas progresses excessively, the same as in the ECR method described above.

Further, the plasma processing apparatus is generally constructed in such a manner that the processing gas is exhausted from the peripheral portion of a sample. In such a case, there is a disadvantage in that the plasma density is higher in the central portion of the sample and lower in the peripheral portion of the sample, and accordingly uniformity in the processing all over the surface of the sample is degraded. In order to eliminate this disadvantage, a ring-shaped bank, that is, a focus ring is provided near the periphery of the sample to stagnate gas flow. However, there is another disadvantage in that reaction products attach onto the bank which becomes a particle producing source to decrease the product yield.

On the other hand, in order to control energy of ions incident to the sample, an RF bias with a sinusoidal waveform is applied to an electrode mounting the sample. The frequency of the RF bias used is several hundreds kHz to 13.56 MHz. However, the energy distribution of incident ions becomes of a double peak type. One of the two peaks is in a lower energy region and the other is in a higher energy region because the ions follow to change in electric field inside a sheath when the RF bias has a frequency within this frequency band. The ions in the higher energy range can process at high speed but damage the sample, and the ions in the lower energy range can process without damage but at low speed. That is, there is a disadvantage in that the processing speed is decreased when one tries to prevent damage of the sample, and the problem of damage arises when one tries to increase the processing speed.

On the other hand, when the frequency of the RF bias is set to a value higher than, for example, 50 MHz, the distribution of incident energy becomes of a single peak type. However, most of the energy is used in plasma generation and consequently the voltage applied to the sheath is substantially decreased. Therefore, there is a disadvantage in that it is difficult to control the energy of the incident ions independently to the plasma density.

Further, in the pulse bias power source method described in Japanese Patent Application Laid-Open No. 62-280378 or Japanese Patent Application Laid-Open No. 6-61182, there is no discussion of a case where a dielectric layer for electrostatic attraction is used between a sample table electrode and a sample while a pulse bias is applied to the sample. When the pulse bias method is directly applied to the electrostatic attracting method, an ion acceleration voltage applied between a plasma and the surface of the sample is decreased by the increase of the voltage generated between both ends of the electrostatic attracting film as ion current flows within one cycle of the RF bias, and consequently the distribution of ion energy is broadened. Therefore, the pulse bias power source method has a disadvantage in that it cannot cope with a required fine pattern processing while temperature of the sample is properly being controlled.

Further, in the conventional sinusoidal wave output bias power source method disclosed in the specification of U.S. Pat. No. 5,320,982, there is a disadvantage in that an impedance of the sheath portion approaches an impedance of the plasma itself or lower when the frequency becomes high. If this occurs, an unnecessary plasma is generated near the sheath in the vicinity of the sample by the bias power source, and accordingly the ions are not effectively accelerated and the distribution of the plasma is also degraded to lose controllability of ion energy by the bias power source.

Furthermore, in plasma processing, in order to improve the performance, it is important to properly control the amount of ions, the amount of radicals and the kinds of radicals. In the past, a gas to be formed into ions and radicals is introduced into a process chamber and the ions and the radicals are produced at the same time by generating a plasma in the process chamber. Therefore, as the processing of the sample becomes very small, it becomes clear that there is a limit in the control of the amount of ions, the amount of radicals and the kinds of radicals.

Further, in regard to an. example of utilizing cyclotron resonance of the VHF band, installation of a bias electric power source for applying a voltage to a sample table and a means for uniformly applying a voltage all over a sample surface are described in Journal of Applied Physics, Japan, Vol.28, No. 10. Further, a processing chamber has a height higher-than 200 mm. Therefore, the construction cannot use

reaction on the surfaces of opposite electrodes effectively, and consequently it is difficult to obtain a high selectivity in this construction.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a plasma processing apparatus and a plasma processing method capable of easily performing precise manufacturing of a fine pattern on a large sized sample having a diameter of 300 mm or more by obtaining a large-sized and uniform plasma in which dissociation of the processing gas does not excessively progress.

Another object of the present invention is to provide a plasma processing apparatus and a plasma processing method capable of performing uniform and high-speed processing, and particularly oxide film processing, all over the surface of a large diameter sample.

A further object of the present invention is to provide a plasma processing apparatus and a plasma processing method capable of improving the selectivity of the etching material of insulator films such as SiO2, SiN, BPSG and the like to the base material.

A still further object of the present invention is to provide a plasma processing apparatus and a plasma processing method capable of improving the selectivity of plasma processing stably with low-damage and high controllability.

A further object of the present invention is to provide a plasma processing apparatus and a plasma processing method capable of performing processing of a required fine pattern manufacturing highly accurately and stably by improving temperature control through electrostatic attracting of a sample.

A still further object of the present invention is to provide a plasma processing apparatus and a plasma processing method capable of controlling the generation of ions and radicals independently.

The present invention is characterized by a plasma processing apparatus comprising a vacuum processing chamber, a plasma generating means including a pair of electrodes, a sample table having a sample mounting surface for mounting a sample to be processed inside the vacuum processing chamber, and an evacuating means for evacuating the vacuum processing chamber, which further comprises a high frequency electric power source for applying a high frequency electric power of a VHF band from 30 MHz to 300 MHz between the pair of electrodes; and a magnetic field forming means for forming a static magnetic field or a low frequency magnetic field in a direction intersecting an electric field generated between the pair of electrodes and the surrounding vicinity by the high frequency electric power source, whereby an electron cyclotron resonance region is formed between the electrodes by the magnetic field and the electric field.

The present invention is also characterized by a plasma processing apparatus comprising a vacuum processing chamber, a plasma generating means including a pair of electrodes, a sample table for mounting a sample to be processed inside the vacuum processing chamber and also serving as one of the electrodes, and an evacuating means for evacuating the vacuum processing chamber, which further comprises a high frequency electric power source for applying an electric power of a VHF band from 50 MHz to 200 MHz between the pair of electrodes; and a magnetic field forming means for forming a static magnetic field or a low frequency magnetic field not weaker than 17 gauss and not stronger than 72 gauss in a direction intersecting an electric field generated between the pair of electrodes and the surrounding vicinity by the high frequency electric power source. The magnetic field forming means is set so that a portion where a component of the magnetic field in a direction along the surface of the sample table becomes maximum is brought to a position on the opposite side of the sample table from the middle of both electrodes. With this arrangement, an electron cyclotron resonance region is formed between the electrodes by the magnetic field and the electric field.

The present invention is further characterized by a method of plasma-processing a sample using a plasma processing apparatus comprising a vacuum processing chamber, a plasma generating means including a pair of electrodes, a sample table for mounting a sample to be processed inside the vacuum processing chamber and also serving as one of said electrodes, and an evacuating means for evacuating the vacuum processing chamber, the method comprising the steps of evacuating inside the vacuum processing chamber by said evacuating means; forming a static magnetic field or a low frequency magnetic field not weaker than 10 gauss and not stronger than 110 gauss in a direction intersecting an electric field between the pair of electrodes by a magnetic field forming means; forming an electron cyclotron resonance region between both electrodes by interaction of the magnetic field and an electric field generated by a high frequency electric power source by applying an electric power of a VHF band from 30 MHz to 300 MHz between the pair of electrodes using the high frequency electric power source; and processing the sample by a plasma produced by the cyclotron resonance of electrons.

According to the present invention, in order not to excessively progress dissociation of a processing gas and in order to obtain a uniform plasma which has a diameter larger than 300 mm and a saturation ion current distribution smaller than ±5%, a high frequency electric power source having a frequency of 30 MHz to 300 MHz, preferably 50 MHz to 200 MHz, is used for generating a plasma. Further, a static magnetic field or a low frequency magnetic field is formed in a direction intersecting an electric field generated between the pair of electrodes. Thereby, an electron cyclotron resonance region is formed between the pair of electrodes along the surface of the sample table and on the opposite side of the sample table from the middle of both electrodes by the magnetic field and the electric field. Thus, the sample is processed using the plasma produced by the cyclotron resonance of electrons.

In regard to the magnetic field, the static magnetic field or the low frequency magnetic field (lower than 1 kHz) partially has an intensity not weaker than 10 gausses and not stronger than 100 gauss, preferably not weaker than 17 gauss and not stronger than 72 gausses. In regard to the gas pressure, it is set to a low pressure from 0.4 Pa to 4 Pa. In addition to these, the distance between the electrodes is set to a value from 30 mm to 100 mm, preferably, 30 mm to 60 mm.

In regard to the frequency f of the high frequency electric power source, by employing VHF in the range 50 MHz≦f≦200 MHz the plasma density is decreased by one order to two orders compared to that in a case of a microwave ECR. The dissociation of gas is also decreased and accordingly generation of unnecessary fluorine atoms and/or molecules and ions are also decreased by one order or more. By using the frequency in the VHF band and the cyclotron resonance, it is possible to obtain a plasma having an appropriately high density and a high processing rate under a pressure condition of 0.4 Pa to 4 Pa. Further, since the

dissociation of processing gas is not excessively progressed, the selectivity to the base material such as Si, SiN or the like is not significantly degraded.

Although the dissociation of processing gas only progresses slightly compared to that in a conventional apparatus of the parallel flat plate electrode type using a frequency of 13.56 MHz, the disadvantage of the small increase in the amount of fluorine atoms and/or molecules and/or ions can be eliminated by providing a material containing silicon or carbon on the surface of the electrodes and/or a wall surface of the chamber, and further by applying a bias voltage to the electrodes and the chamber or by exhausting fluorine through coupling the fluorine with hydrogen using a gas containing hydrogen atom.

Further, according to the present invention, a portion where the component of the magnetic field parallel to the sample table between the electrodes is set at a position on the side opposite to the sample table from the middle of both electrodes and the magnetic field intensity on the surface of the sample table mounting the sample parallel to the sample table is set below 30 gauss, preferably, below 15 gauss. Thereby, a Lorentz force (E×B) acting on electrons near the sample mounting surface is made small, and consequently occurrence of non-uniformity by the electron drift effect due to the Lorentz force on the sample mounting surface can be eliminated.

The present invention is characterized by the fact that the cyclotron resonance effect of electrons is larger in a portion within a range from the periphery of a sample to the outer side of the periphery than in the center of the sample so as to increase the generation of plasma in the portion within the range from the periphery of the sample to the outer side of the periphery than in the center of the sample. A means for decreasing the effect of the cyclotron resonance of electrons can be attained by increasing the distance between the cyclotron resonance region and the sample, or decreasing the degree of intersection between the magnetic field and the electric field.

When a gradient of the magnetic field near the cyclotron resonance region Bc is steepened to narrow the ECR resonance region, the cyclotron effect can be weakened. The ECR resonance region is formed in a range of a magnetic field intensity B, $Bc(1-a) \leqq B \leqq Bc(1+a)$ where $0.05 \leqq a \leqq 0.1$.

A large amount of ions are generated in the ECR resonance region since dissociation of the processing gas progresses there. On the other hand, a large amount of radicals are generated in the region other than the ECR resonance region since the dissociation of the processing gas does not progress significantly compared to progression in the ECR resonance region. By adjusting a width of the ECR resonance region and a high frequency electric power applied to the upper electrode, it is possible to independently control the amount of generated ions and the amount of generated radicals appropriate for processing the sample.

The present invention is characterized by a plasma processing apparatus comprising a vacuum processing chamber, a sample table for mounting a sample to be processed in the vacuum processing chamber, and a plasma generating means including a high frequency electric power source, which further comprises an electrostatic attracting means for holding the sample onto the sample table by an electrostatic attracting force; and a pulse bias applying means for applying a pulse bias voltage to the sample; the high frequency electric power source applying a high frequency voltage of 10 MHz to 500 MHz, the vacuum processing chamber being depressurized to 0.5 to 4.0 Pa.

The present invention is further characterized by a plasma processing apparatus comprising a vacuum processing chamber, a sample table for mounting a sample to be processed in the vacuum processing chamber, and a plasma generating means including a high frequency electric power source, which further comprises an electrostatic attracting means for holding said sample onto the sample table by an electrostatic attracting force; a pulse bias applying means connected to the sample table and for applying a pulse bias voltage to the sample; and a voltage suppressing means for suppressing a voltage rise generated by applying a pulse bias voltage corresponding to an electrostatic attracting capacity of the electrostatic attracting means.

The present invention is also characterized by a method of plasma processing comprising the steps of placing a sample on one of a pair of electrodes opposite to each other provided in a vacuum processing chamber; holding the sample onto the electrode by an electrostatic attracting force; introducing an etching gas into an environment in which the sample is placed; evacuating the environment to a pressure condition of 0.5 Pa to 4.0 Pa; forming the etching gas into a plasma under the pressure condition by applying a high frequency electric power of 10 MHz to 500 MHz; etching the sample by the plasma; and applying a pulse bias voltage to the one of the pair of electrodes.

The present invention is further characterized by a method of plasma processing comprising the steps of placing a sample on one of the electrodes opposite to each other; holding the placed sample onto the electrode by an electrostatic attracting force; introducing an etching gas into an environment in which the sample is placed; forming the introduced etching gas into a plasma; etching the sample by the plasma; and applying a pulse bias voltage having a pulse width of 250 V to 1000 V and a duty ratio of 0.05 to 0.4 to the one of electrodes during etching, whereby an insulator film, such as SiO_2, SiN, BPSG or the like, in the sample is plasma-processed.

According to another characteristic of the present invention, by applying a pulse-shaped bias voltage having a proper characteristic to a sample table having an electrostatic attracting means with a dielectric layer for electrostatic attracting, it is possible to appropriately control the temperature of a sample and stably perform required fine pattern processing. That is, the plasma processing apparatus comprises an electrostatic attracting means for holding a sample onto a sample table by an electrostatic attracting force, and a pulse bias applying means connected to the sample table for applying a pulse bias voltage to the sample table. The pulse bias voltage has a period of 0.2 to 2 μs and a duty cycle in the positive direction less than one-half, and is applied to the sample through a capacitance element.

According to a further characteristic of the present invention, in regard to a voltage suppressing means for suppressing change in a voltage generated by applying the pulse bias voltage corresponding to an electrostatic attracting capacity of the electrostatic attracting means, the voltage suppressing means is designed so that voltage change due to an electrostatic attracting film of the electrostatic attracting means during one cycle of pulse is suppressed to one-half of the pulse bias voltage. In detail, this can be attained by reducing a thickness of an electrostatic chuck film made of a dielectric material provided on the surface of the lower electrode, or by employing a material having a large specific dielectric coefficient. Further, it is also possible to employ a method of suppressing an increase of voltage applied to both ends of the dielectric layer by shortening the period of the pulse bias voltage.

According to a further characteristic of the present invention, by applying a pulse bias voltage having a pulse width of 250 V to 1000 V and a duty ratio of 0.05 to 0.4 to the one of electrodes during etching, it is possible to improve the plasma processing selectivity of the base material of an insulator film, such as SiO_2, SiN, BPSG or the like.

The present invention is characterized by a plasma processing apparatus comprising a vacuum processing chamber, a sample table for mounting a sample to be processed in the vacuum processing chamber, and a plasma generating means, which further comprises an electrostatic attracting means for holding the sample onto the sample table by an electrostatic attracting force; a bias applying means for applying a bias voltage to the sample; a radical supplying means having a means decomposing a gas for generating radicals in advance and for supplying a required amount of the radicals to the vacuum processing chamber; a means for supplying a gas for generating ions to the vacuum processing chamber; and a plasma generating means for generating a plasma in the vacuum processing chamber, wherein SiO_2 is used as the sample.

The present invention is further characterized by a plasma processing apparatus comprising a vacuum processing chamber, a sample table for mounting a sample to be processed in the vacuum processing chamber, and a plasma generating means including a high frequency electric power source, which further comprises an electrostatic attracting means for holding the sample onto the sample table by an electrostatic attracting force; a pulse bias applying means for applying a pulse bias voltage to the sample; a radical generating plasma supplying means for forming a gas for generating radicals into a plasma in advance and for supplying a required amount of the radicals to the vacuum processing chamber; and the plasma generating means for supplying a gas for generating ions to the vacuum processing chamber and for generating a plasma in the vacuum processing chamber, whereby the high frequency electric power source applying a high frequency voltage of 10 MHz to 500 MHz, the vacuum processing chamber can be depressurized to 0.5 to 4.0 Pa.

According to another characteristic of the present invention, by controlling the amounts and the qualities of ions and radicals independently and applying a pulse bias voltage having an appropriate characteristic to a sample table having an electrostatic attracting means with a dielectric layer for electrostatic attracting, it is possible to properly control temperature of a sample and to stably perform required fine pattern processing.

Further, it is possible to improve the selectivity of plasma processing with a stable and better control condition by controlling the amounts and the qualities of ions and radicals independently and by obtaining a narrow ion energy distribution.

Furthermore, the amounts and the qualities of ions and radicals are independently controlled, and a voltage suppressing means, which suppresses change in a voltage corresponding to an electrostatic attracting capacity of the electrostatic attracting means generated by applying the pulse bias voltage, is designed so that voltage change due to an electrostatic attracting film of the electrostatic attracting means during one cycle of pulse is suppressed to one-half of the pulse bias voltage. In detail, this can be attained by reducing a thickness of an electrostatic chuck film made of a dielectric material provided on the surface of the lower electrode, or by employing a material having a large specific dielectric coefficient. Further, it is also possible to employ a method of suppressing an increase of voltage applied to both ends of the dielectric layer by shortening the period of the pulse bias voltage.

According to a further characteristic of the present invention, since the amounts and the qualities of ions and radicals are independently controlled and a pulse bias voltage having a pulse width of 250 V to 1000 V and a duty ratio of 0.05 to 0.4 is applied to the one of electrodes during etching, it is possible to improve the plasma processing selectivity of the base material to an insulator film, such as SiO_2, SiN, BPSG or the like.

Further according to a characteristic of the present invention, the amounts and the qualities of ions and radicals are independently controlled, a high frequency electric power source for generating a plasma of a high frequency voltage of 10 MHz to 500 MHz is used, and gas pressure in the processing chamber is set to a low pressure of 0.5 Pa to 4.0 Pa. Thereby, it is possible to obtain a stable plasma. Further, by using such a high frequency voltage, the plasma is well ionized and the control of selectivity during processing a sample is improved.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a vertical cross-sectional view showing an embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. **2** is a graph showing an example of change in plasma density when the frequency of a high frequency electric power source for generating a plasma is changed under a condition where a magnetic field for producing cyclotron resonance of electrons is applied.

FIG. **3** is a graph showing energy gains k of electrons obtained from a high frequency electric field under conditions with and without cyclotron resonance.

FIG. **4** is a graph showing the relationship between intensity of a magnetic field and an ion acceleration voltage V_{DC} induced in a sample, as well as the deviation ΔV of an induced voltage in the sample when an upper electrode of a magnetron discharge electrode is grounded and a lower electrode is applied with a magnetic field B and a high frequency electric power.

FIG. **5** is a graph showing a magnetic field characteristic of the plasma etching apparatus of FIG. **1**.

FIG. **6** is a graph explaining an ECR region of the plasma etching apparatus of FIG. **1**.

FIGS. **7(A)** and **7(B)** are charts showing examples of preferable output wave-forms used in a pulse bias electric power source in accordance with the present invention.

FIGS. **8(1)** to **8(5)** are charts showing electric potential wave-forms on a sample surface and probability distribution of ion energy when T_0 is varied while a pulse duty ratio (T_1/T_0) is being kept constant.

FIG. **9** is a chart showing an electric potential wave-form on a sample surface and probability distribution of ion energy when T_0 is varied while a pulse duty ratio is being kept constant.

FIG. **10** is a graph showing the relationship between the pulse OFF period (T_1-T_0) and maximum voltage V_{CM} during one cycle of a voltage induced between both ends of an electrostatic attracting film.

FIG. **11** is a graph showing the relationship between pulse duty ratio and (V_{DC}/V_p).

FIG. **12** is a graph showing energy dependence of the silicon etching rate ESi and oxide film etching rate $ESiO_2$ when chlorine gas of 5 mTorr is formed in a plasma.

FIG. 13 is a graph showing ion energy distributions of the oxide film etching rate $ESiO_2$ and silicon etching rates ESi as an example of etching of a oxide film when CF4 gas of 5 mTorr is formed in a plasma.

FIG. 14 is a vertical cross-sectional view showing another embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 15 is a vertical cross-sectional view showing a further embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 16 is a graph explaining an ECR region of the plasma etching apparatus of FIG. 15.

FIG. 17 is a graph showing a magnetic field distribution characteristic of the plasma etching apparatus of FIG. 15.

FIG. 18 is a vertical cross-sectional view showing a further embodiment of a plasma etching apparatus in accordance with the present invention.

FIG. 19 is a graph showing a magnetic field distribution characteristic of the plasma etching apparatus of FIG. 18.

FIG. 20 is a vertical cross-sectional view showing a further embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 21 is a vertical cross-sectional view showing a further embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 22 is a graph showing a magnetic field distribution characteristic of the plasma etching apparatus of FIG. 21.

FIG. 23 is a cross-sectional side view showing the main portion of a further embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 24 is a vertical cross-sectional view showing the plasma etching apparatus of FIG. 23.

FIG. 25 is a view showing another embodiment of a magnetic field forming means.

FIG. 26 is a vertical cross-sectional view showing another embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 27 is a vertical cross-sectional view showing another embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 28 is a vertical cross-sectional view showing another embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 29 is a graph showing a magnetic field distribution characteristic of the plasma etching apparatus of FIG. 28.

FIG. 30 is a vertical cross-sectional view showing a further embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

FIG. 31 is a vertical cross-sectional view showing an embodiment of a plasma etching apparatus of a two-electrode type which is a modification of one shown in FIG. 1.

FIG. 32 is a graph showing the relationship between frequency of a plasma generating electric power source and a lowest gas pressure condition for stable discharge.

FIG. 33 is a graph showing the relationship between frequency of a pulse bias electric power source and cumulative electric power.

FIG. 34 is a vertical cross-sectional view showing an embodiment of a plasma etching apparatus of an induction coupling discharge type and a non-magnetic field type among external energy supplying discharge types to which the present invention is applied.

FIG. 35 is a vertical cross-section view showing a further embodiment of a plasma etching apparatus in accordance with the present invention.

FIG. 36 is a vertical cross-sectional front view showing a part of a microwave processing apparatus to which the present invention is applied.

FIG. 37 is a vertical cross-sectional view showing a further embodiment of a plasma etching apparatus in accordance with the present invention.

FIG. 38 is a vertical cross-sectional front view showing a further embodiment of a plasma processing apparatus in accordance with the present invention.

FIG. 39 is a vertical cross-sectional view showing a further embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention which is capable of controlling ions and radicals independently.

FIG. 40 is a vertical cross-sectional view showing a further embodiment of a plasma etching apparatus of a two-electrode type in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Embodiments of the present invention will be described below. FIG. 1 shows a first embodiment of a plasma etching apparatus using opposed electrodes to which the present invention is applied.

Referring to FIG. 1, a processing chamber 10 of a vacuum container has a pair of opposed electrodes composed of an upper electrode 12 and a lower electrode 15. On the lower electrode 15 a sample 40 is mounted. The distance of a gap between the electrodes 12 and 15 is preferably not smaller than 30 mm in order to suppress a pressure difference on the sample to within 10% when the sample has a large diameter of about 300 mm or larger. In order to decrease amounts of fluorine atoms, molecules and ions, the distance is desired to be not larger than 100 mm, preferably, not larger than 60 mm from the view point of effectively using a reaction product on the surfaces of the upper and the lower electrodes. A high frequency electric power source 16 for supplying a high frequency energy is connected to the upper electrode 12 through a matching box 162. The reference character 161 indicates a high frequency electric power modulating signal source. Between the upper electrode 12 and the ground there is connected a filter 165 which becomes a low impedance to the frequency component of a bias electric power source 17 and becomes a high impedance to the frequency component of the 15S high frequency electric power source 16. The reference character 13 indicates an insulator member made of aluminum oxide or the like.

The area of the upper electrode 12 arranged nearly parallel to the sample table is larger than an area of the sample 40 to be processed so that voltage of the bias electric power source 17 is effectively and uniformly applied to the sheath on the sample table.

An upper electrode cover 30 of a fluorine removing plate made of silicon, carbon or SiC is provided on the bottom surface of the upper electrode 12. Further, a gas introducing chamber 34 is provided having a gas diffusion plate 32 for diffusing gas in a desired distribution. A gas necessary for processing operations such as etching the sample is supplied to the processing chamber 10 from a gas supplying unit 36 through the gas diffusion plate 32 of the gas introducing chamber 34, and holes 38 are provided in the in the upper electrode 12 and the upper electrode cover 30. An outer

chamber 11 is evacuated by a vacuum pump 18 connected to the outer chamber 11 through a valve 14 to adjust pressure in the processing chamber 10 to a process pressure. A discharge confining ring 37 is provided in the processing chamber 10 to increase plasma density and make the reaction inside the processing chamber uniform. The discharge confining ring 37 has gaps for evacuation.

Above the upper electrode 12, there is provided a magnetic field forming means 200 which forms a magnetic field intersecting with an electric field E formed between the electrodes at a right angle and parallel to the surface of the sample 40. The magnetic field forming means 200 has a core 201, an electromagnetic coil 202 and an insulator member 203. A material for constructing the upper electrode 12 is a non-magnetic conductor such as aluminum, an aluminum alloy or the like. A material for constructing the processing chamber 10 is a non-magnetic material such as aluminum, an aluminum alloy, aluminum oxide, quartz, SiC or the like. The core 201 is formed in an axial-rotating symmetrical structure having a nearly E-shaped cross section with the cores 201A, 201B so as to form a magnetic field B of which the magnetic fluxes extend from the upper central portion of the processing chamber 10 toward the upper electrode 12 and then extend along and in parallel to the upper electrode 12 toward the periphery of the upper electrode. The magnetic field formed between both electrodes by the magnetic field forming means 200 has a portion of a static magnetic field or a low frequency magnetic field (lower than 1 kHz) having an intensity of 10 gauss to 110 gauss, preferably, 17 gauss to 72 gauss for producing cyclotron resonance.

It is well-known that the relationship between an intensity B_c (gauss) of the magnetic field for producing cyclotron resonance and a frequency f (MHz) of the plasma forming high frequency source can be expressed as $B_c=0.357\times f$ (MHz).

The two electrodes 12 and 15 in the present structure may have some indent portions or projecting portions depending on, for example, a requirement of a plasma forming characteristic as far as the pair of opposite electrodes 12 and 15 are substantially in parallel to each other. In such a two-electrode type, the electric field distribution between the two electrodes can be easily made uniform. Accordingly, generation of plasma by cyclotron resonance can be made uniform comparatively easily by improving the uniformity of the magnetic field intersecting with the electric field at a right angle.

The lower electrode 15 mounting and holding the sample 40 has a two-pole type electrostatic chuck 20. That is, the lower electrode 15 is composed of a first lower electrode 15A in the outer side and a second lower electrode 15B arranged in the inner side through an insulator member 21, and an electrostatic attracting dielectric layer 22 (hereinafter referred to as an electrostatic attracting film) is provided on the upper surfaces of the first and the second lower electrodes. A direct current source 23 is connected to the first and second lower electrodes through coils 24A, 24B for cutting a high frequency component to apply a direct current voltage between both lower electrodes so that the second lower electrode 15B is charged positively. Thereby, the sample 40 is attracted and held onto the lower electrode 15 by a Coulomb force acting between the sample 40 and both lower electrodes through the electrostatic attracting film 22. A material usable for the electrostatic attracting film 22 is a dielectric material such as aluminum oxide, titanium oxide containing aluminum oxide or the like. As the electric source 23, a direct current source of several hundred volts can be used.

A pulse bias electric power source 17 for supplying a pulse bias having an amplitude of 20 V to 1000 V is connected to the lower electrodes 15A, 15B through blocking capacitors 19A, 19B for cutting Direct current components, respectively.

Although the electrostatic chuck of a two-pole type has been described above, an electrostatic chuck of another type such as a single-pole type or an e-pole type ($n\geqq 3$) may be applicable.

When etching is performed, the sample 40 of an object to be processed is mounted on the lower electrode 15 in the processing chamber 10 and attracted by the electrostatic chuck 20. On the other hand, a gas required for etching the sample 40 is supplied to the processing chamber 10 from the gas supplying unit 36 through the gas introducing chamber 34. The outer chamber 11 is vacuum-pumped by the vacuum pump 18 to be evacuated and depressurized so that pressure of the processing chamber becomes a processing pressure of the sample, for example, a pressure of 0.4 Pa to 4.0 Pa. Then, a high frequency electric power of 30 MHz to 300 MHz, preferably 50 MHz to 200 MHz, is output from the high frequency electric power source 16 to form the processing gas in the processing chamber 10 into a plasma.

By the high frequency electric power of 30 MHz to 300 MHz and the portion of static magnetic field of 10 gauss to 110 gauss formed by the magnetic field forming means 200, cyclotron resonance of electrons is generated between the upper electrode 12 and the lower electrode 15 to form a plasma having a low pressure, 0.4 to 4.0 Pa in this case, and a high density.

On the other hand, a pulse bias voltage of 20 V to 1000 V having a period of 0.1 μs to 10 μs, preferably 0.2 μs to 5 μs, and a duty in a positive pulse portion of 0.05 to 0.4 is applied to the lower electrode 15 from the pulse bias electric power source 17 to etch the sample while the electrons and the ions in the plasma are being controlled.

The etching gas is formed in a desired distribution by the gas diffusion plate 32 and then introduced into the processing chamber 10 through the holes 38 bored in the upper electrode 12 and the upper electrode cover 30.

Materials which can be used for the upper electrode cover 30, include carbon, silicon or a material containing carbon or silicon which removes the components of fluorine and/or oxygen to improve the selectivity to the resist and/or silicon to the base material.

In order to improve the micro workability of a large diameter sample, it is preferable that a plasma generating high frequency electric power source 16 having a high frequency is used to attempt to stabilize discharge in a low pressure region. In the present invention, the plasma generating high frequency electric power source 16 is connected to the upper electrode 12 in order to obtain a plasma which is a low pressure of 0.4 Pa to 4.0 Pa and a plasma density of 5×10^{10} to 5×10^{11} cm^{-3}, and dissociation of the processing gas is not excessively progressed and has a uniform and large diameter. On the other hand, an ion energy controlling bias electric source 17 is connected to the lower electrode 15 mounting the sample, and the distance between the electrodes is set between 30 mm to 100 mm.

Further, using a VHF voltage of 30 MHz to 300 MHz, preferably 50 MHz to 200 MHz, for the plasma generating high frequency electric power source 16, and by the interaction with the portion of the static magnetic field or the low frequency (lower than 1 kHz) magnetic field having an intensity of 10 gauss to 110 gauss, preferably 17 gauss to 72 gauss, cyclotron resonance of electrons is formed between the upper electrode 12 and the lower electrode 15.

FIG. 2 shows an example of the change in plasma density when the frequency of a high frequency electric power source for generating a plasma is changed under a condition where a magnetic field for producing cyclotron resonance of electrons is applied. The gas used is argon with 2 to 10% of C_4F_8 added thereto, and the pressure of the processing chamber is 1 Pa. The plasma density in the figure is shown as a normalized value by letting the density in a case of a microwave ECR with f=2450 MHz be 1 (one). The dashed line in the figure shows a result obtained in a case without a magnetic field.

The plasma density is lower by one order to two orders compared to that in the microwave ECR when the frequency is in the range of 50 MHz≦f≦200 MHz. Further, dissociation of the gas is also decreased and generation of unnecessary fluorine atoms, molecules and ions is decreased by one order or more. By using the frequency in the VHF band and cyclotron resonance, a plasma having appropriately high density, namely, a plasma density above 5×10^{10} cm^{-3} in absolute value is obtained, and a high rate processing is also possible under a low pressure of 0.4 Pa to 4.0 Pa. Furthermore, since dissociation of the gas is not excessively progressed, the selectivity of an insulator film such as SiO_2 to the base material such as Si or SiN is not appreciably degraded.

When the frequency is within the range of 50 MHz≦f≦200 MHz, the dissociation of the processing gas is slightly progressed compared to that in a conventional apparatus of parallel flat plate electrode type using a frequency of 13.56 MHz, and the disadvantage of a small increase in the amount of fluorine atoms and/or molecules and/or ions can be eliminated by providing a material containing silicon or carbon to the surface of the electrodes and wall surface of the chamber, and further by applying a bias voltage to the electrodes and the wall surface of the chamber or by exhausting fluorine through coupling the fluorine with hydrogen using a gas containing hydrogen atoms.

When the frequency of the high frequency electric power source is above 200 MHz, particularly, above 300 MHz, the plasma density becomes high. However, it is not preferable since the dissociation of the processing gas becomes large and fluorine atoms and/or molecules and ions are extremely increased, and consequently the selectivity to the base material is largely degraded.

FIG. 3 shows an energy gains k of electrons obtained from a high frequency electric field under conditions with and without cyclotron resonance. Letting an energy obtained by an electron during one cycle of a high frequency source under a condition without the magnetic field be e_0, and an energy obtained by an electron during one cycle of a high frequency source under a condition applied with a cyclotron resonance magnetic field $B_c=2\pi f\cdot(m/e)$ be e_1, e_0 and e_1 are expressed as the following equations:

$$e_0=(e^2E^2/2m)\{v/(w^2+v^2)\}$$

$$e_1=(e^2E^2v/4m)\{1/(v^2+(w-wc)^2)+1/(v^2+(w+wc)^2\} \qquad \text{(Equation 1)}$$

where E is the intensity of the electric field.

Letting the ratio ($=e_1/e_0$) be k, k is expressed by the following equation, where m is the mass of an electron, e is the charge of an electron and f is charged frequency:

$$k=(1/2)\ (w^2+v^2)\{1/(v^2+(w-wc)^2)+1/(v^2+(w+wc)^2\},$$

where v is collision frequency, w is exciting angular frequency, and wc is cyclotron angular frequency.

In general, the value k becomes larger as the gas pressure is lower and the frequency is higher. FIG. 3 is a result obtained using argon gas in which k≧150 when f≧50 MHz under a condition of pressure P=1 Pa, and dissociation of the processing gas is progressed even under a low pressure compared to in a case without the magnetic field. The cyclotron resonance effect is rapidly decreased under a condition of pressure P=1 Pa when the frequency is below nearly 20 MHz. It can be understood from the characteristic shown in FIG. 2 that when the frequency is lower than 30 MHz, there is little difference in the result from that in a case without the magnetic field, and the cyclotron resonance effect is small.

Although the cyclotron resonance effect can be increased by decreasing the gas pressure, electron temperature of the plasma is increased and there occurs an opposite effect in that the dissociation of the gas is excessively progressed when the gas pressure is lower than 1 Pa. In order to suppress the excessive dissociation of gas and to increase the plasma density above 5×10^{10} cm^{-3}, the gas pressure is set to at a value in the range of 0.4 Pa to 4 Pa, preferably, 1 Pa to 4 Pa.

In order to attain an effective cyclotron resonance effect, it is necessary to set the value k to several tens or larger. It can be understood from FIG. 2 and FIG. 3 that in order to effectively use the cyclotron resonance effect without excessively progressing dissociation of the gas, it is required to set the gas pressure to a value of 0.4 Pa to 4 Pa and to use a VHF of 30 MHz to 300 MHz, preferably, 50 MHz to 200 MHz for plasma generating high frequency electric power.

FIG. 4 shows the relationship between intensity of a magnetic field and an ion acceleration voltage V_{DC} induced in a sample, deviation ΔV of an induced voltage in the sample when an upper electrode of a magnetron discharge electrode is grounded and a lower electrode is applied with a magnetic field B and a high frequency electric power. As the intensity of magnetic field is increased, the ion acceleration voltage V_{DC} becomes small by Lorentz force action on electrons and consequently the plasma density is increased. However, since the intensity of magnetic field B is as large as 200 gauss in the conventional magnetron discharge type, there is a disadvantage in that uniformity of plasma density in the surface is degraded and the deviation ΔV of the induced voltage becomes large to increase damage of the sample.

It can be understood from FIG. 4 that in order to decrease the deviation ΔV to 1/5 to 1/10 of that in the conventional magnetron discharge type having a magnetic field intensity of 200 gauss, in order to eliminate sample damage the intensity of the magnetic field B is set to a value below 30 gauss near the sample surface, preferably, set to a value smaller than 15 gauss.

A cyclotron resonance region is formed between the upper electrode **12** and the lower electrode **15** and slightly on the side of the upper electrode from the middle position of both electrodes. The abscissa in FIG. 5 indicates distance from the sample surface (the lower electrode **15**) to the upper electrode **12**, and the ordinate indicates magnetic field. FIG. 5 shows an example obtained under a condition of an applied frequency f_1 of 100 MHz, B_c of 37.5 G and a distance between the electrodes of 50 mm, in which an ECR region is formed in a position about 30 mm from the sample surface.

As described above, in the present invention, a portion where the component of magnetic field parallel to the lower electrode **15** (the sample mounting surface) becomes maximum is set on the upper electrode surface or on the side of

the upper electrode from the middle position between the two electrodes. By doing so, the intensity of the magnetic field parallel to the sample on the lower electrode surface is set to a value smaller than 30 gauss, preferably, smaller than 15 gauss to make the Lorentz force (EXB) acting on electrons near the lower electrode surface a small value, and consequently it is possible to eliminate the non-uniformity in the plane of plasma density due to the electron drift effect caused by Lorentz force on the lower electrode surface.

According to the magnetic field forming means **200** in the embodiment of FIG. **1**, the ECR region is formed nearly in the same level from the lower electrode **15** (the sample mounting surface) except for the central portion of the sample, as shown in FIG. **6**. Therefore, a sample having a large diameter can be plasma-processed uniformly. However, the ECR region in the central portion of the sample is formed in a position of higher level from the sample mounting surface. Since the distance between the ECR region and the sample table is larger than 30 mm, ions and radicals are diffused and averaged in the gap. Therefore, there is no problem in a general plasma processing operation. However, in order to perform plasma-processing all over the sample uniformly, it is preferable that the ECR region is formed in a position of the same level from the sample surface all over the surface of the sample, or the ECR region is formed in a position slightly closer to the periphery of the sample table compared to the level of the ECR region in the central portion. The method of forming such a plasma will be described later.

As described above, in the embodiment of the present invention shown in FIG. **1**, since a VHF voltage of 30 MHz to 300 MHz forming the plasma generating high frequency electric power source **16** is used and dissociation of the processing gas is progressed by electron cyclotron resonance, it is possible to obtain a stable plasma even when gas pressure inside the processing chamber is as low as 0.4 Pa to 4 Pa. Further, since ion collision in the sheath is reduced, moving directions of ions during processing the sample **40** are well aligned to improve the verticality in the fine pattern processing.

In regard to the surrounding of the processing chamber **10**, since the plasma is confined in the vicinity of the sample **40** by the discharge confining ring **37**, the plasma density is increased and attaching of unnecessary deposits to portions outside the discharge confining ring **37** is minimized.

A material used for the discharge confining ring **37** is a semiconductor material or a conductor material such as carbon, silicon or SiC. When the discharge confining ring **37** is connected to a high frequency electric power source to cause sputtering by ions, it is possible to decrease attaching of deposits to the ring **37** and also to remove fluorine.

Since fluorine can be removed by providing a suscepctive cover **39** made of carbon, silicon or a material containing carbon or silicon on the insulator member **13** near the sample when an insulator film such as SiO_2 is plasma-processed using a gas containing fluorine, the selectivity can be improved. In this case, when the thickness of the insulator member **13** in a portion under the susceptive cover **39** is thinned to 0.5 mm to 5 mm, the effect described above can be promoted by the sputtering effect by ions.

Further, an electrostatic attracting circuit is formed through the lower electrode **15** (**15**A, **15**B) and the sample **40** interposing the electrostatic attracting film **22** of dielectric material. In this state, the sample **40** is held and maintained onto the lower electrode **15** by an electrostatic force. Along the back side surface of the sample **40** held by the electrostatic attracting force, a heat transfer gas such as helium, nitrogen, argon or the like is supplied. The heat transfer gas is filled between the back side surface of the sample **40** and the lower electrode **15**, and the heat transfer gas is set to a pressure of several hundreds pascals to several thousands pascals. It is considered that the electrostatic attracting force is nearly zero between the indented portions existing in gaps and acts only in the projecting portions of the lower electrode **15**. However, as described later, since it is possible to set an attracting force large enough to withstanding the pressure of the heat transfer gas by properly setting a voltage of the direct current electric power source **23**, the sample **40** cannot be moved or blown off by the heat transfer gas.

The electrostatic attracting film **22** acts to decrease the bias function of pulse bias to ions in the plasma. The function exists in a conventional method of biasing using a sinusoidal electric power source, but the problem does not clearly appear. However, the problem becomes clear in the pulse bias method since the characteristic of the pulse bias method of narrow ion energy width is lost.

The present invention is characterized by a voltage suppressing means that is provided in order to suppress the increase of the voltage difference generated between the ends of the electrostatic attracting film **22** accompanied by application of the pulse bias to increase the pulse bias effect.

As an example of the voltage suppressing means, it is preferable that the voltage change (V_{CM}) in one cycle of the bias voltage generated between the ends of the electrostatic attracting film accompanied by application of the pulse bias is lower than one-half of the voltage (V_p) of the pulse bias. In detail, there is a method for increasing the electrostatic capacity of the dielectric member by thinning a thickness of the electrostatic attracting film made of a dielectric material provided on the surface of the lower electrode, or by employing a material having a large specific dielectric coefficient.

Further, as another example of the voltage suppressing means, there is a method of suppressing the increase of the voltage V_{CM} by shortening the period of the pulse bias voltage. Furthermore, it is also considered that the electrostatic attracting circuit and the pulse bias voltage applying circuit are separately arranged in different positions, for example, another different electrode opposite to the electrode mounting and holding the sample, or a third electrode provided separately.

Description will be made in detail below on the relationship between the voltage change (V_{CM}) in one cycle of the bias voltage generated between the ends of the electrostatic attracting film and the pulse bias voltage which should be brought by the voltage suppressing means in accordance with the present invention, referring to FIG. **7** to FIG. **13**.

FIGS. **7**(A) and **7**(B) show an example of a desirable output waveform used in the pulse bias power source **17** in accordance with the present invention. In the figure, pulse amplitude is v_p, pulse period is T_0, and positive direction pulse width is T_1.

When the wave-form of FIG. **7**(A) is applied to a sample though a blocking capacitor and an electrostatic attracting dielectric layer (hereinafter referred to as electrostatic attracting film), the voltage wave-form on the surface of the sample under a steady-state condition where a plasma is generated by another power source becomes as shown in FIG. 7 (B). Referring to the labelling of FIG. **7**(B), V_{DC} is direct current component voltage of the wave-form V_f is floating potential of the plasma, and V_{CM} is maximum voltage during one cycle of the voltage produced between both ends of the electrostatic attracting film.

The portion (1) which is positive voltage to V_f in FIG. 7(B) is a portion where only electron current is mainly dragged, the portion which is negative voltage to V_f is a portion where ion current is dragged, and the portion V_f is a portion where electrons and ions are balanced. The voltage V_f is generally several volts to several tens of volts.

In the description according to FIG. 7(A) and thereafter, it is assumed that the capacitance of the blocking capacitor and the capacitance of the insulator member near the sample surface are sufficiently larger than the capacitance of the electrostatic attracting film (hereinafter referred to as electrostatic attracting capacitance).

The value V_{CM} is expressed by the following equation:

$$V_{CM}=(q/c)=\{i_i\times(T_0-T_1)\}/\{(\epsilon_r\epsilon_0/d)\times K\} \quad \text{(Equation 2)}$$

In this equation, q is ion current density (averaged value) entering into the sample during the period of (T_0-T_1) i_i is ion current density, d is film thickness of the electrostatic attracting film, K is electrode cover ratio of the electrostatic attracting film ($\leqq 1$), ϵ_r is the specific dielectric constant of the electrostatic attracting film, and ϵ_0 is dielectric constant of vacuum (constant value).

FIGS. 8(A) to 8(E) and FIG. 9 show electric potential wave-forms on the sample surface and probability distribution of ion energy when To is varied while a pulse duty ratio (T_1/T_0) is being kept constant. Therein, $T_{01}:T_{02}:T_{03}:T_{04}:T_{05}=16:8:4:2:1$.

As shown in FIG. 8(A), when the pulse period T_0 is too large, the electric potential on the sample surface is largely deformed from a rectangular wave-form and becomes a triangular wave-form. The distribution of ion energy becomes constant from a low ion energy region to a high ion energy region, as shown in FIG. 9, which is not preferable.

As shown in FIGS. 8(B) to (E), as the pulse period T_o is decreased to small, the value (VCM/VP) becomes smaller than 1 (one), and the ion energy distribution is also narrowed.

In FIGS. 8(A) to 8(E) and FIG. 9, the relationship $T_o=T_{01}$, T_{02}, T_{03}, T_{04}, T_{05} corresponds to $(V_{CM}/v_p)=1$, 0.63, 0.31, 0.16, 0.08.

Next, FIG. 10 shows the relationship between pulse OFF period (T_1-T_0) and maximum voltage V_{CM} during one cycle of a voltage induced between both ends of the electrostatic attracting film.

The solid bold line (line for reference condition) in FIG. 10 shows change of the value V_{CM} in a plasma having a medium density of ion current density $i_i=5$ mA/cm^2 when about 50% of the area of the electrode (K=0.5) is flattened to touch to the back side of the sample 40, and is covered with aluminum oxide containing titanium oxide ($\epsilon_r=10$) with a thickness of 0.3 mm.

It can be understood from FIG. 10 that as the pulse OFF period (T_1-T_0) is increased, the voltage V_{CM} induced between both ends of the electrostatic attracting film is increased proportional to the period and becomes higher than the pulse voltage v_p generally used.

For example, in a plasma etching apparatus, the pulse voltage v_p is generally limited as follows in connection to occurrence of damage, selectivity to base material and/or a mask, a shape and so on:

For gate etching: 20 volts$\leqq v_p<$100 volts

For metal etching: 50 volts$\leqq v_p<$200 volts

For oxide film etching: 250 volts$\leqq v_p<$1000 volts

When it is tried to satisfy the condition $(V_{CM}/V_p)\leqq 0.5$, to be described later, in the reference condition, the limit in the pulse OFF period (T_1-T_0) becomes as follows:

For gate etching: $(T_1-T_0)\leqq 0.15$ μs

For metal etching: $(T_1-T_0)\leqq 0.35$ μs

For oxide film etching: $(T_1-T_0)\leqq 1.2$ μs

When T_0 approaches to 0.1 μs, unnecessary plasma is generated and the bias electric source is not effectively used for ion acceleration since the impedance of the ion sheath approaches to or becomes lower than the impedance of the plasma. Thereby, controllability of ion energy by the bias electric power source is degraded. Therefore, it is desired that the period T_0 is larger than 0.1 μs, preferably, larger than 0.2 μs.

In a gate etching apparatus in which v_p can be suppressed to a low value, it is necessary to employ a material having a specific dielectric constant as high as 10 to 100 for the electrostatic attracting film, for example, a dielectric constant ϵ_r of Ta_2O_5 is 25, and to also decrease the film thickness, for example, to a thickness of 10 μm to 400 μm, preferably, to a thickness of 10 μm to 100 μm, without reducing the insulating withstanding voltage.

In FIG. 10, there are also shown the values of V_{CM} when electrostatic capacitance per unit area is increased by 2.5 times, 5 times and 10 times. Even if an electrostatic attracting film is improved, it is thought that the electrostatic capacitance c can be increased by several times in the present situation. Assuming $V_{CM}\leqq 300$ volts, $c\leqq 10c_0$, the following relation can be obtained:

$$0.1\ \mu s\leqq(T_0-T_1)\leqq 10\ \mu s.$$

A portion effective for plasma processing by ion acceleration is the portion (T_0-T_1), and therefore it is preferable that the pulse duty (T_1/T_0) is as small as possible.

FIG. 11 shows (V_{DC}/v_p) which means an efficiency of plasma processing taking time average into consideration. It is preferable to make (T_1/T_0) small and (V_{DC}/V_p) large.

Assuming $(V_{DC}/V_p)\geqq 0.5$ as an efficiency of plasma processing and taking a condition to be described later $(V_{DC}/V_p)\leqq 0.5$, the pulse duty becomes $(T_1/T_0)\leqq$approximately 0.4.

The pulse duty (T_1/T_0) is effective for ion energy control when it is small. However, when it is unnecessarily small, a pulse width T_1, becomes as small as 0.05μ and consequently the pulse bias contains frequency components in the range of several tens of MHz. As a result, it becomes difficult to separate from the plasma generating high frequency component which is to be described later. As shown in FIG. 11, since decrease of (V_{DC}/v_p) in the range of $0\leqq(T_1/T_0)\leqq 0.05$ is small, no problem occurs when (T_1/T_0) is set to a value above 0.05.

As an example of gate etching, FIG. 12 shows an energy dependence of the silicon etching rate ESi and oxide 20 film etching rate $ESiO_2$ when chlorine gas of 10 mTorr is formed in a plasma. The silicon etching rate ESi becomes a constant value in a low ion energy region. In a region of ion energy above approximately 10 V, ESi increases as the ion energy increases.

On the other hand, the etching rate $ESiO_2$ for the oxide film of the base material is zero when the ion energy is smaller than nearly 20 V, and when the ion energy exceeds nearly 20 V, the etching rate $ESiO_2$ increase as the ion energy is increased.

As a result, when the ion energy is below nearly 20 V, there is a region where the selectivity to the base material $ESi/ESiO_2$ becomes ∞ (infinity). When the ion energy is above nearly 20 V, the selectivity $ESi/ESiO_2$ to the base material rapidly decreases as the ion energy is increased.

As an example of etching of an oxide film (SiO, BPSG, HISO, TEOS or the like) as a kind of insulator films, FIG.

13 shows ion energy distributions of the oxide film etching rate $ESiO_2$ and silicon etching rates ESi when C_4F_8 gas of 1.0 Pa is formed in a plasma.

The oxide film etching rate $ESiO_2$ becomes negative an d deposits are produced when the ion energy is low. The oxide film etching rate $ESiO_2$ steeply increases at the ion energy of nearly 400 V, and after that gradually increases. On the other hand, the etching rate ESi for silicon to be used as the base material is switched from negative (etching) to positive (etching) at an ion energy higher than the ion energy where $ESiO_2$ is switched from negative to positive, and then gradually increases.

As the result, the selectivity $ESi/ESiO_2$ to the base material becomes ∞ (infinity) at an ion energy where $ESiO_2$ is switched from negative to positive, and in the ion energy above the switching point the selectivity $ESi/ESiO_2$ steeply decreases as the ion energy increases.

When the results of FIG. **12** and FIG. **13** are applied to a practical process, ion energy is set to an appropriate value by adjusting the bias electric power source with taking the values of ESi, $ESiO_2$, $ESi/ESiO_2$, and the magnitude of the value $ESi/ESiO_2$.

A better characteristic can be obtained by switching the ion energy just before and just after etching, that is, etching until exposing a base film, with giving a priority to the etching rate just before the etching and giving a priority to the selectivity just after the etching.

The characteristic shown in FIG. **12** and FIG. **13** is a characteristic for a case where the ion energy distribution is limited in a narrow range. Since an etching rate for a case where the ion energy distribution spreads in a wide range is expressed by the time averaged value, it cannot be set at the optimum value and accordingly the selectivity is substantially degraded.

According to an experiment, when the value (V_{DC}/V_p) was smaller than about 0.3, a deviation of ion energy was smaller than nearly ±15%, and a high selectivity higher than **30** was attained with the characteristic of FIG. **12** and FIG. **13**. Further, as far as $(V_{DC}/V_p) \leqq 0.5$, the selectivity was improved compared to a conventional sinusoidal wave bias method.

As described above, as the voltage suppressing means for suppressing the voltage change (V_{CM}) in one cycle of the bias voltage generated between the ends of the electrostatic attracting film, it is preferable that the voltage change (V_{CM}) is lower than one-half of the voltage (V_p) of the pulse bias. In detail, there is a method to decreasing a thickness of the electrostatic chuck film **22** made of a dielectric material provided on the surface of the lower electrode **15**, or by employing a material having a large specific dielectric coefficient. Further, there is a method to suppress the voltage change between the ends of the electrostatic attracting film by shortening the period of the pulse bias voltage to 0.1 μs to 10 μs, preferably, 0.2 μs to 5 μs (corresponding to repeating frequency of 0.2 MHz to 5 MHz) so that the pulse duty (T_1/T_0) is set as $0.05 \leqq (T_1/T_2) \leqq 0.4$.

Furthermore, it is possible to make the voltage change (V_{CM}) in one cycle of the bias voltage generated between the ends of the electrostatic attracting film satisfy the above-described condition $(V_{DC}/V_p) \leqq 0.5$.

An embodiment of using the vacuum processing chamber for etching of an insulator film (SiO, BPSG, TEOS, HISO or the like) will be described below.

A processing gas **36** used for the etching operation is composed of C_4F_8 of 1 to 5%, Ar of 90 to 95% and O_2 of 0 to 5%; or C_4F_8 of 1 to 5%, Ar of 70 to 90%, O_2 of 0 to 5% and CO of 10 to 20%. The plasma generating high frequency electric power source **16** used has a higher frequency, for example 40 MHz, compared to a conventional one to stabilize discharge under a low pressure range of 1 to 3 Pa.

When dissociation of the processing gas progresses to exceed the necessary amount by using the high frequency of the plasma generating high frequency power source **16**, the output of the high frequency power source **16** is ON-OFF controlled or level modulation controlled using a high frequency electric power modulating signal source **161**. When the level is high, ions are generated more than generation of radicals, and when the level is low, radicals are generated more than generation of ions. An ON time (or the high level time for the level modulation) used is 5 to 50 μs, and an OFF time (or the low level time for the level modulation) used is 10 to 200 μs, while a period used is 20 to 250 μs. By doing so, it is possible to avoid unnecessary dissociation and to attain a desired ion-radical ratio.

A modulating period of the plasma generating high frequency power source is generally longer than the period of the pulse bias. Therefore, the modulating period of the plasma generating high frequency power source is set to a value of an integer times the period of the pulse bias to optimize the phase between them. By doing so, the selectivity can be improved.

On the other hand, ion energy is controlled so that ions in the plasma are accelerated and vertically irradiated onto the sample by applying a pulse bias voltage. By using an electric power source having, for example, a pulse bias period T of 0.65 μs, a pulse width T1 of 0.15 μs and a pulse amplitude V_p of 800 V as the pulse bias power source **17**, it is possible to perform plasma processing having a better characteristic in which the width of ion energy distribution is ±15% and the selectivity to the base material is 20 to 50.

Another embodiment of a plasma etching apparatus of two-electrode type in accordance with the present invention will be described below, referring to FIG. **14**. Although this embodiment has a similar construction as shown by FIG. **1**, a different point of this embodiment from FIG. **1** is that the lower electrode **15** holding the sample has a single pole type electrostatic chuck **20**. An electrostatic attracting dielectric layer **22** is provided on the upper surface of the lower electrode **15**, and the positive side of the direct current source **23** is connected to the lower electrode **15** through a coil **24** for cutting the high frequency component. Further, the pulse bias electric power source **17** for supplying a positive pulse bias voltage of 20 V to 1000 V is also connected to the lower electrode through a blocking capacitor **19**.

Discharge confining rings **37A**, **37B** are provided in the periphery of the processing chamber **10** to increase a plasma density and to minimize attaching of unnecessary deposits onto the outside portions of the discharge confining rings **37A**, **37B**. In the discharge confining rings **37A**, **37B** of FIG. **14**, a diameter of the bank portion of the discharge confining ring **37A** in the lower electrode side is formed smaller than a diameter of the bank portion of the discharge confining ring **37B** in the upper electrode side so that distribution of reaction products around the sample is made uniform.

A material used for the discharge confining rings **37A**, **37B**, at least for the side facing the processing chamber side, is a semiconductor or a conductor such as carbon, silicon or SiC. Further, a bias electric power source **17A** of 100 kHz to 13.56 MHz for the discharge confining ring is connected to the ring **37A** in the lower electrode side through a capacitor **19A**, and the ring **37B** in the upper electrode side is constructed so that a part of the voltage of the high frequency electric power source **16** is applied to the ring **37B**

in the upper electrode side. Thereby, attaching of deposits onto the rings 37A, 37B due to the sputtering effect of ions is decreased and the fluorine removing effect is provided.

The reference characters 13A, 13C of FIG. 14 are insulator members made of aluminum oxide or the like, and the reference character 13B is an insulator member having a conductor such as SiC, glassy carbon, Si or the like.

When the conductivity of the rings 37A, 37B is low, conductors made of a metal are embedded inside the rings 37A, 37B and distance between the surface of the ring and the embedded conductor is made small. Thereby, the high frequency electric power easily radiates from the surfaces of the rings 37A, 37B to decrease reduction of the sputter effect.

The upper electrode cover 30 is fixed to the upper electrode 12 generally only in the peripheral portion of the cover with bolts 250. A gas is supplied to the upper electrode cover 30 from the gas supply unit 36 through the gas introducing chamber 34, the gas diffusion plate 32 and the upper electrode 12. The holes provided in the upper electrode cover 30 have a very small diameter of 0.3 to 1 mm to reduce the likelihood of the occurrence of abnormal discharge in the hole. The gas pressure in the upper portion of the upper electrode cover 30 is a fraction of one atmospheric pressure to one-tenth of one atmospheric pressure. For example, a force of nearly 100 kg acts on the upper electrode cover 30 having a diameter of larger than 300 mm as a whole. Therefore, the upper electrode cover 30 is deformed in a convex shape to the upper electrode 12 and accordingly a gap is produced having several hundreds micro-meters near the central portion.

In that case, when the frequency of the high frequency electric power source 16 is increased up to approximately more than 30 MHz, resistance in the lateral direction of the upper electrode cover 30 cannot be neglected and particularly the plasma density near the central portion is decreased. In order to solve this problem, the upper electrode cover 30 is fixed to the upper electrode 12 in portions near the center side of the upper electrode cover, not the peripheral portion. In the embodiment of FIG. 14, the upper electrode cover is fixed to the upper electrode 12 in several portions near the central side of the upper electrode cover 30 using bolts 251 made of a semiconductor such as SiC or carbon or an insulator such as aluminum oxide to make distribution of the high frequency field applied from the upper electrode 12 side uniform.

The method of fixing the upper electrode cover 30 to the upper electrode 12 at least near the center of the cover is not limited to using the bolts 251 described above. For example, the upper electrode cover 30 may be fixed to the upper electrode 12 using a substance having adhesiveness all over the surface or at least near the center of the upper electrode cover.

In FIG. 14, the sample 40 to be processed is mounted on the lower electrode 15 and attracted by the electrostatic chuck 20, that is, by a Coulomb force produced between both ends of the electrostatic attracting film 22 by positive charge by the direct current electric power source 23 and negative charge supplied from the plasma.

The operation of this apparatus is the same as that of the two-electrode type plasma etching apparatus shown in FIG. 1. When etching is performed, the sample 40 of an object to be processed is mounted on the lower electrode 15 and attracted by an electrostatic force. While a processing gas is being supplied to the processing chamber 10 from the gas supplying unit 36, on the other hand, the processing chamber is evacuated and depressurized by the vacuum pump 18 so that pressure of the processing chamber becomes a processing pressure of the sample, that is, a pressure of 0.5 Pa to 4.0 Pa. Then, the high frequency electric power source 16 is switched on to apply a high frequency electric power of 20 MHz to 500 MHz, preferably 30 MHz to 100 MHz, between the electrodes 12 and 15 to form the processing gas into a plasma.

On the other hand, a positive pulse bias voltage of 20 V to 1000 V having a period of 0.1 μs to 10 μs, preferably 0.2 μs to 5 μs, and a duty in a positive pulse portion of 0.05 to 0.4 is applied to the lower electrode 15 from the pulse bias electric power source 17 to etch the sample while the electrons and the ions in the plasma are being controlled.

By applying the pulse bias voltage in such a manner, ions and/or-electrons in the plasma are accelerated and vertically irradiated onto the sample to perform highly precise shape control or highly precise selectivity control. The characteristics required for the pulse bias power source 17 and the electrostatic attracting film 22 are the same as in the embodiment of FIG. 1, and accordingly detailed description will be omitted here.

A further embodiment according to the present invention will be described below, referring to FIG. 15 to FIG. 17.

Although this embodiment is similar to the plasma etching apparatus of the two-electrode type construction shown in FIG. 1, a different point of this embodiment from FIG. 1 is in construction of the magnetic field forming means 200. The core 201 of the magnetic field forming means 200 is eccentrically arranged and driven by a motor 204 so as to be rotated at a speed of several rotations per minute to several tens of rotations per minute around an axis corresponding to the center of the sample 40. The core 201 is grounded.

In order to perform plasma-processing all over the surface of the sample highly accurately, cyclotron resonance effect of electrons is larger in the peripheral portion or the portion outside of the peripheral portion than in the center so that generation of plasma becomes large in the peripheral portion or the portion outside of the peripheral portion of the sample than in the center of the sample. However, in the embodiment of FIG. 1, there is no ECR region in the central portion of the sample and the plasma density near the center of the sample sometimes becomes too low, as shown in FIG. 6.

In the embodiment of FIG. 15, the magnetic field distribution is varied by rotation of the eccentric core 201 of the magnetic field forming means 200, and accordingly in the central portion of the sample the ECR region is formed in a low position from the sample surface at time t=0 and $t=T_0$, and formed in a high position from the sample surface at time $t=(\frac{1}{2})T_0$. Since the core 201 is rotated at a speed of several rotations per minute to several tens of rotations per minute, the averaged value of the magnetic field intensity in the middle portion between the electrodes in the direction parallel to the sample surface becomes nearly the same value by the time averaging due to the rotation, as shown in FIG. 17. That is, the ECR region is formed in nearly the same level from the sample surface except for the peripheral portion of the sample.

As shown by dash-and-dot lines in the core 201 portion of FIG. 15, the thickness of the core composing the magnetic circuit in the side near the eccentric central core is formed thin and the thickness of the core composing the magnetic circuit in the side far from the eccentric central core is formed thick. By doing so, uniformity of the magnetic field intensity is further improved.

A still further embodiment in accordance with the present invention will be described below, referring to FIG. 18 and FIG. 19. Although this embodiment is similar to the plasma

etching apparatus of the two-electrode type construction shown in FIG. 15, a different point of this embodiment from FIG. 15 is in construction of the magnetic field forming means **200**. The core **201** of the magnetic field forming means **200** has a concave surface edge **201A** in a portion corresponding to the center of the processing chamber and also has another edge **201B** in the side position of the processing chamber. By operation of the concave surface edge **201A**, the magnetic flux B has a component in the inclined direction. As a result, distribution of the magnetic field is varied and the component of the magnetic field intensity in the direction parallel to the sample surface is formed to be more uniform compared to on the case of FIG. 1, as shown in FIG. 19.

A further embodiment in accordance with the present invention will be described below, referring to FIG. 20. Although this embodiment is similar to the plasma etching apparatus of the two-electrode type construction shown in FIG. 15, a different point of this embodiment from FIG. 15 is in construction of the magnetic field forming means **200**. The core **201** of the magnetic field forming means **200** is of a fixed type, and forms a magnetic circuit together with a core **205** arranged in a position corresponding to the central portion of the processing chamber. The core **205** is rotated around an axis passing through the center of the edge **201A** together with an insulator member **203**. By such a construction, the same as the embodiment of FIG. 15, the averaged position of the ECR region near the central portion of the sample is formed in nearly the same level from the sample surface all over the surface of the sample.

A still further embodiment of a two-electrode type plasma etching apparatus in accordance with the present invention will be described below, referring to FIG. 21 and FIG. 22. In this embodiment, the magnetic field forming means **200** has two pairs of coils **210**, **220** in the circumferential portion of the processing chamber, and a rotating magnetic field is formed by successively switching the direction of the magnetic field in each of the pairs of coils as shown by the arrows (1), (2), (3), (4). The position of the center 0–0' of the coils **210**, **220** is set at a level in the upper electrode **12** side from the middle level between the electrodes **12** and **15**. Thereby, the apparatus is constructed so that the magnetic field intensity on the sample **40** becomes smaller than 30 gauss, preferably, smaller than 15 gauss.

The distribution of the magnetic field intensity for each portion on the sample surface can be adjusted by appropriately choosing the position and the diameter of the coils **210**, **220** so as to increase plasma generation in the periphery or the outer side of the periphery of the sample.

A further embodiment of a two-electrode type plasma etching apparatus in accordance with the present invention will be described below, referring to FIG. 23 and FIG. 24. In this embodiment, the magnetic field forming means **200** has a pair of coils **210'** arranged in an arc-shape in a horizontal plane along the circumference of the circular processing chamber. The polarity of the magnetic field is varied with a constant period as shown by the arrows (1), (2) in FIG. 23 by controlling current flowing in the pair of coils **210'**.

Since the magnetic flux expands with respect to a vertical plane in the central portion of the processing chamber as shown by the dashed lines in FIG. 24, the intensity of the magnetic field in the central portion of the processing chamber is reduced. However, the pair of coils **210'** are curved along the processing chamber, and the magnetic flux B is concentrated in the central portion of the processing chamber. Therefore, the intensity of the magnetic field in the central portion of the processing chamber can be increased compared to the embodiment of FIG. 22. In other words, in the embodiment of FIG. 23, it is possible to suppress a decrease in the magnetic field in the central portion of the processing chamber compared to in the embodiment of FIG. 22, and, accordingly, the uniformity of the magnetic field on the sample mounting surface of the sample table can be improved.

Further, by varying the polarity of the magnetic field with a certain period, drift effect of E×B can be reduced.

In this type, two pair of coils as in the embodiment of FIG. 22 may be employed as the magnetic field forming means **200**.

Further, instead of the arc-shaped coil **210'** the magnetic field forming means **200** may employ a convex coil **210'** shown in FIG. 25 which is formed by combining a plurality of straight shaped coil sections arranged along the circumference of the circular processing chamber **10**. In this case, the magnetic flux B concentrates in the central portion of the processing chamber and, accordingly, the same effect as in the embodiment of FIG. 23 can be obtained.

Furthermore, as shown in FIG. 26, the center axis of a pair of coils may be inclined with respect to a vertical plane so as to approach the sample surface in the central portion of the processing chamber. According to this embodiment, since the magnetic field intensity in the central portion of the processing chamber can be increased and the magnetic field intensity in the peripheral portion of the processing chamber can be decreased, the uniformity of the magnetic field on the sample mounting surface of the sample table can be improved. In order to make the magnetic field intensity uniform, it is preferable that the inclining angle θ of the center axis of the coil is set from 5 degrees to 25 degrees.

Further, as shown in FIG. 27, a pair of coils **210B** are arranged near a pair of coils **210A**. By controlling currents flowing in the two pair of coils, the position of the ECR resonance as well as the gradient of the magnetic field near the position of the ECR resonance are varied to change the width of the ECR resonance region. By optimizing the width of the ECR resonance region for each process, it is possible to obtain an ion/radical ratio suitable for each process.

It is possible to further improve the uniformity of magnetic field intensity distribution and the controllability by properly combining the embodiments of FIG. 23 to FIG. 27 described above, if necessary.

A still further embodiment of a two-electrode type plasma etching apparatus in accordance with the present invention will be described below, referring to FIG. 28 and FIG. 29. In this embodiment, a part of the processing chamber is made of a conductor and grounded. On the other hand, the magnetic field forming means **200** has coils **230**, **240** in the peripheral portion and the upper portion of the processing chamber **10**. The direction of the magnetic flux B formed by the coil **230** and the direction of the magnetic flux B' formed by the coil **240** cancel each other in the central portion of the processing chamber **10**, and superpose each other in the peripheral portion and the outer portion of the peripheral portion of the processing chamber **10**, as shown by the arrows. As a result, the distribution of the magnetic field intensity at each position of the sample surface becomes as shown in FIG. 29.

In addition to this, in the portion of the mounting surface for the sample **40**, the direction of the electric field and the direction of the magnetic field between the upper electrode **12** and the lower electrode **15** are the same. On the other hand, in the portion outside the mounting surface for the sample **40**, the component of the magnetic field in the vertical direction intersecting with the component of electric

field in the lateral direction at a right angle is formed in the peripheral portion of the upper electrode **12** and the portion between the upper electrode **12** and the wall of the processing chamber.

Therefore, according to the embodiment of FIG. **38**, the cyclotron resonance effect of electrons in the central portion of the sample can be decreased and generation of plasma in the peripheral portion and the outside portion of the peripheral portion of the sample can be increased.

A further embodiment in accordance with the present invention will be described below, referring to FIG. **30**. In the two-electrode type plasma etching apparatus shown in FIG. **1**, there are some cases where sufficient ion energy cannot be obtained with the high frequency electric power f_1 applied from the high frequency electric power source **16** to the upper electrode **12**. In such a case, this embodiment increases the ion energy to 100 V to 200 V by applying a high frequency voltage f_3 having a frequency, for example, below 1 MHz from a low frequency electric power source **163** to the upper electrode **12** as a bias. Here, the reference characters **164**, **165** indicate filters.

An embodiment of a two-electrode type plasma etching apparatus of non-magnetic field type in accordance with the present invention will be described below, referring to FIG. **31**.

As described above, in order to improve micro workability of a sample, it is preferable that a plasma generating high frequency electric power source **16** has a higher frequency and discharge under a low gas pressure is stabilized. In the embodiment of the present invention, the pressure processing a sample in the processing chamber is set to 0.5 to 4.0 Pa. By setting the gas pressure in the processing chamber **10** to a low pressure below 40 mTorr, probability of ion collision in the sheath is decreased. Therefore, in processing a sample **40**, directivity of ions is increased and accordingly it becomes possible to perform vertical fine pattern. However, in order to attain the same processing rate under a pressure below 5 mTorr, the exhausting system and the high frequency electric power source become large in size, and dissociation of the processing gas occurs excessively due to increase of electron temperature, as a result, the processing characteristic is likely to be degraded.

In general, between a frequency of a plasma generating electric power source for a pair of electrodes and a minimum gas pressure capable of stably discharging, there is relationship that the lowest gas pressure for stable discharge is decreased as the frequency of the electric power source is increased and the distance between the electrodes is increased. In order to avoid ill effects such as attaching of deposits onto surrounding walls and onto the discharge confining ring **37** and to effectively perform a function of removing fluorine or oxygen by the upper electrode cover **30**, the susceptive cover **39** and the resist in the sample, it is preferable that the distance between the electrodes is set to a value shorter than 50 mm which corresponds to a distance smaller than 25 times of mean-free-path at the maximum gas pressure of 40 mTorr. On the other hand, in order to attain stable discharge, the distance between the electrode is required to be 2 to 4 times (4 mm to 8 mm) or larger of the mean-free-path at the maximum gas pressure (40 mTorr).

In the embodiment shown in FIG. **31**, since a high frequency electric power of 20 MHz to 500 MHz, preferably 30 MHz to 200 MHz, is used as the plasma generating high frequency electric power source **16**, it is possible to obtain a stable plasma and to improve micro workability even if the gas pressure in the processing chamber is set to a low pressure of 0.5 to 4.0 Pa. Further, by using such a high frequency electric power, dissociation of gas plasma is improved and controllability of selectivity during processing of a sample is improved.

In the embodiments of the present invention described above, the occurrence of interference between the output of the pulse bias electric power source and the output of the plasma generating electric power source can be considered. Therefore, the countermeasure for this problem will be described below.

In an ideal rectangular pulse having a pulse width of T_1, a pulse period of T_0 and rise/fall speeds of infinity, as shown in FIG. **33**, 70% to 80% of the electric power is included in the frequency range of $f \leqq 3f_0$ ($f_0=(1/T_1)$). However, the wave-form actually applied has rise/fall speeds of finite values, convergence of electric power is further improved and 90% of electric power can be included in the frequency range of $f \leqq 3f_0$.

In order to uniformly apply a pulse bias having a high frequency component of $3f_0$ over the surface of a sample, it is preferable to provide opposing electrodes parallel to the sample surface and to ground a pulse bias having a frequency component within a range of $f \leqq 3f_0$ where $3f_0$ is obtained from Equation 3 as follows:

$$3f_0=3\cdot(10^6/0.2)=15 \text{ MHz, when } T=0.2\ \mu s\ 3f_0=30 \text{ MHz, when } T=0.1\ \mu s \quad \text{(Equation 3)}$$

In the embodiment shown in FIG. **31**, a countermeasure is provided for interference between the output of the pulse bias electric power source and the output of the plasma generating electric power source. That is, in the plasma etching apparatus, the plasma generating high frequency electric power source **16** is connected to the upper electrode **12** opposite to the sample **40**. In order to set the upper electrode **12** to the ground level of the pulse bias, the frequency f_1 of the plasma generating electric power source **16** is set to a value larger than $3f_0$ described above and the upper electrode **12** and the ground level are connected with a band eliminator **141** of which the impedance is large around $f=f_1$ and small for the other frequencies.

On the other hand, the sample table **15** and the ground level are connected with a band pass filter **142** of which the impedance is small around $f=f_1$ and large for the other frequencies. By constructing in such a way, the interference between the output of the pulse bias electric power source **17** and the output of the plasma generating electric power source **16** can be suppressed to a level which creates no problem and a better bias can be applied to the sample **40**.

FIG. **34** shows an embodiment of a plasma etching apparatus of the induction coupling discharge type and the non-magnetic field type among the external energy supplying discharge type to which the present invention is applied. The reference character **52** indicates a flat coil, and the reference character **54** indicates a high frequency electric power source for applying a high frequency voltage of 10 MHz to 250 MHz to the flat coil. The plasma etching apparatus of the induction coupling discharge type can generate a stable plasma with a lower frequency and under a lower gas pressure compared to the type shown in FIG. **10**. On the contrary, dissociation of gas is apt to be progressed. Therefore, unnecessary dissociation is prevented by modulating the output of the high frequency electric power source **1** using the high frequency electric power source modulating signal source **161**, as shown in FIG. **1**. The processing chamber **10** of a vacuum vessel comprises a sample table **15** which mounts the sample **40** on the electrostatic attracting film **22**.

When etching is performed, the sample **40** of an object to be processed is mounted on the lower electrode **15** and

attracted by an electrostatic force. While a processing gas is being supplied to the processing chamber **10** from the gas supplying unit, not shown, on the other hand, the processing chamber is evacuated and depressurized by the vacuum pump so that pressure of the processing chamber becomes a processing pressure of the sample, that is, a pressure of 0.5 Pa to 4.0 Pa. Then, a high frequency electric power of 13.56 MHz is applied from the high frequency electric power source **54** to the flat coil **52** to form a plasma in the processing chamber **10**. The sample **40** is etched using the plasma. On the other hand, during etching, a pulse bias voltage having a period of 0.1 μs to 10 μs, preferably 0.2 μs to 5 μs is applied to the lower electrode **15**. The amplitude of the pulse bias voltage used is in a different range depending on the kind of the film, as described in the embodiment of FIG. 1. By applying the pulse bias voltage in such a manner, ions in the plasma are accelerated and vertically irradiated onto the sample to perform highly precise shape control or highly precise selectivity control. Accordingly, it is possible to perform accurate etching even if a resist mask pattern of the sample is of a submicron pattern.

In a plasma etching apparatus of the induction coupling discharge type and the non-magnetic field type, a Faraday shield plate **53** having a gap, which is grounded, and a thin shield plate protective insulator plate **54** having a thickness of 0.5 mm to 5 mm may be provided on the processing chamber **10** side of the induction high frequency magnetic field output portion. Since the capacitance component between the coil and the plasma is reduced by providing the Faraday shield plate **53**, it is possible to reduce energy of ions impinging on a quartz plate under the coil **52** of FIG. **34** and the shield plate protective insulator plate **54** to reduce damage of the quartz plate and the insulator plate, and to prevent foreign from mixing into the plasma.

Further, since the Faraday shield plate **53** also serves as a grounded electrode for the pulse bias electric power source **17**, it is possible to apply the pulse bias between the sample **40** and the Faraday shield plate **53** uniformly. In this case, no filter is required between the upper electrode and the sample table **15**.

FIG. **36** is a vertical cross-sectional front view showing a part of a microwave processing apparatus to which the present invention is applied. A pulse bias electric power source **17** and a direct current source **13** are connected to a lower electrode **15** also serving as a sample table **15** mounting a sample **40** on an electrostatic attracting film **22**. The reference character **41** indicates a magnetron of a microwave oscillating source, the reference character **42** indicates a microwave guide tube, and the reference character **43** indicates a quartz plate for vacuum-sealing a processing chamber **10**, noting that these elements are used to supply the microwave to the processing chamber. The reference character **47** indicates a first solenoid coil for supplying a magnetic field, and the reference character **48** indicates a second solenoid coil for supplying a magnetic field. The reference character **49** indicates a process gas supplying system which supplies a process gas for performing processing such as etching, film-forming and so on into the processing chamber **10**. The processing chamber **10** is evacuated by a vacuum pump, not shown. The characteristics required for the pulse bias electric power source **17** and the electrostatic chuck **20** are the same as in the embodiment of FIG. **1**, and accordingly detailed description will be omitted here.

When etching is performed, the sample **40** of an object to be processed is mounted on the lower electrode **15** and

attracted by an electrostatic force. While a processing gas is being supplied to the processing chamber **10** from the gas supplying unit **49**, on the other hand, the processing chamber is evacuated to a vacuum by the vacuum pump so that pressure of the processing chamber becomes a processing pressure of the sample, that is, a pressure of 0.5 Pa to 4.0 Pa. Then, the magnetron **41** and the first and the second solenoid coils **47**, **48** are switched on, and a microwave generated in the magnetron **41** is guided to the processing chamber through the wave-guide tube **42** to produce a plasma. The sample **40** is etched using the plasma. On the other hand, during etching, a pulse bias voltage having a period of 0.1 μs to 10 μs, preferably 0.2 μs to 5 μs is applied to the lower electrode **15**.

By applying the pulse bias voltage in such a manner, ions in the plasma are accelerated and vertically irradiated onto the sample to perform high precision shape control or high precision selectivity control. Thereby, it is possible to perform accurate etching processing even if a resist mask pattern of the sample is of a submicron pattern.

In the plasma etching apparatuses in accordance with the present invention depicted in FIG. **1** and the following figures, the direct current voltage of the electrostatic attracting circuit and the pulse voltage of the pulse bias electric power source circuit may be generated by superposing each other. Thereby, both circuits can be constructed in common. Further, the electrostatic attracting circuit and the pulse bias electric power source circuit may be separately provided so that the pulse bias does not adversely affect the electrostatic attraction.

Instead of the electrostatic attracting circuit in the embodiment of the plasma etching apparatus of FIG. **1**, another attracting means such as a vacuum attracting means may be employed.

The above-mentioned plasma processing apparatuses having the electrostatic attracting circuit and the pulse bias voltage applying circuit in accordance with the present invention can be applied not only to an etching processing apparatus but also to a plasma processing apparatus such as a CVD apparatus by changing the etching gas to a CVD gas.

A description will be provided below regarding a further embodiment of a plasma etching apparatus capable of submicron plasma-processing by overcoming conventional disadvantages and by controlling quantity and quality of ions and radicals, referring to FIG. **37** depicting the further embodiment in accordance with the present invention.

A first plasma generating portion is provided in a place upstream of a vacuum processing chamber where a sample is placed noting that the first plasma generating portion is different from the vacuum processing chamber. Quasi-stable atoms generated in the first plasma generating portion are injected into the vacuum processing chamber, and then the quasi-stable atoms are formed into a second plasma in the vacuum processing chamber. In addition to the plasma etching apparatus shown in FIG. **1**, an ion/radical forming gas supply unit **60** and a plasma generating chamber **62** for generating the quasi-stable atoms are provided. Further, a route for introducing a gas containing the quasi-stable atoms into the vacuum processing chamber and an introducing route connected to the ion/radical forming gas supply unit are provided in the upper electrode **12**.

The characteristics of this embodiment are as follows.

(1) A gas supplied from the quasi-stable atom forming gas supply unit **36** is formed into a plasma by being applied with a high frequency electric power in the quasi-stable atom forming plasma generating chamber **62**, and a required amount of quasi-stable atoms are generated in advance to be

introduced into the processing chamber **10**. In order to efficiently generate the quasi-stable atoms, pressure of the quasi-stable atom forming plasma generating chamber **62** is set to a high pressure of several hundred mTorr to several tens of mTorr.

(2) On the other hand, a gas is introduced into the processing chamber from the ion/radical forming gas supply unit **60**.

(3) A high frequency voltage having a comparatively small power is output from the plasma generating electric power source **16** to form a plasma in the processing chamber **10**. Since ions are efficiently formed with electrons having a low energy lower than nearly 5 eV because of injection of the quasi-stable atoms, it is possible to obtain a plasma which is in a low electron temperature lower than 6 eV, preferably, lower than 4 eV and which has a very small amount of high energy electrons above 15 eV. Therefore, the radical forming gas is not excessively dissociated and accordingly a necessary quantity and a necessary quality of the radicals can be maintained. On the other hand, a quantity of the ions can be controlled by the amount of the quasi-stable atoms generated in the quasi-stable atom forming plasma generating chamber **62** and the amount of ion forming gas from the ion/radical forming gas supply unit **60**.

Since the quantity and the quality of the ions and radicals can be controlled in such a manner, a better performance can be attained even in submicron plasma processing. The radical forming gas used is CHF_3, CH_2F_2, or a fluorocarbon gas such as C_4F_4 or CF_4, or adding a gas containing C and H such as C_2H_4, CH_4, CH_3OH, if necessary. The quasi-stable forming gas used is a gas composed of one kind or two kinds of rare gas as a base gas. The ion forming gas used is a gas having the following characteristic which efficiently forms ions.

The gas used as an ion forming gas is one having an ionization level which is lower than an energy level of the quasi-stable atoms, or a gas having an ionization level which is higher than an energy level of the quasi-stable atoms, noting, however, that the difference is as small as 5 eV or less.

It is also possible to use the quasi-stable atom forming gas or the radical forming gas described above instead of the ion forming gas, though the performance is likely to be degraded.

FIG. **38** shows a still further embodiment in accordance with the present invention in which a quantity and a quality of ions and radicals are controlled. This embodiment is the same as the embodiment of FIG. **37** in its basic idea. In FIG. **37**, when the distance between the quasi-stable atom forming plasma chamber **62** and the vacuum processing chamber **10** is large, decay of the quasi-stable atoms in the passage becomes large. This embodiment is a countermeasure for such a case. The reference character **41** indicates a magnetron of a microwave oscillating source, the reference character **42** indicates a microwave guide tube, the reference character **43** indicates a quartz plate for vacuum-sealing a first plasma generating chamber **45** and allowing the microwave to pass through, and the reference character **44** is a quartz plate for diffusing gas. In the first plasma generating chamber **45**, a plasma is generated by the microwave under a gas pressure of several hundred mTorr to several tens of mTorr to form quasi-stable atoms.

Since the distance between the place generating the quasi-stable atoms and the vacuum processing chamber in the apparatus of FIG. **38** is short compared with in the apparatus of FIG. **37**, it is possible to inject the quasi-stable atoms with a high density and accordingly an amount of ions in the vacuum processing chamber **10** can be increased. By maintaining the processing chamber **10** at a pressure of 5 to 50 mTorr and using the high frequency electric power source **16** having a frequency above 20 MHz, a high density and low electron temperature plasma having a density of order of 10^{10} to $10^{11}/cm^3$ and an electron temperature of 5 eV, preferably, 3 eV and dissociation of the ion forming gas is progressed while avoiding dissociation of CF_2 which requires a dissociation energy of 8 eV. As a result, on the surface of the sample **40**, the following reaction is mainly progressed with the assistance of incident ions accelerated at several hundred volts by the bias electric power source **17**.

$$SiO_2+2CF_2 \rightarrow SiF_4\uparrow+2CO\uparrow$$

Since Si and SiN used as a base material are not etched by CF_2, it is possible to perform oxide film etching with a high selectivity.

Increases in the amount of fluorine due to partial dissociation of CF_2 can be decreased by virtue of the upper electrode cover **30** being made of silicon, carbon or SiC.

As described above, by adjusting the radical forming gas and the ion forming gas the ratio of ions and radicals in the processing chamber **10** can be independently controlled, and consequently the reaction on the surface of the sample **40** can be easily controlled.

The plasma processing apparatus having the electrostatic attracting circuit and the pulse bias voltage applying circuit in accordance with the present invention can be applied not only to an etching processing apparatus but also to a plasma processing apparatus such as a CVD apparatus by changing the etching gas to a CVD gas.

FIG. **39** shows a further embodiment in accordance with the present invention in which a quantity and a quality of ions and radicals are independently controlled. In FIG. **39**, the radical forming gas used is CHF_3, CH_2F_2, or a fluorocarbon gas such as C_4F_4 or CF_4, or adding a gas containing C and H such as C_2H_4, CH_4, CH_3OH, if necessary. The radical forming gas is introduced into the radical forming plasma generating chamber **62** through a valve **70** shown by an arrow A in FIG. **39**.

In the radical forming plasma generating chamber **62**, a plasma is generated by applying an output having a frequency of several MHz to several tens of MHz of an RF power source **63** to the coil **65** under a pressure of several hundred mTorr to several tens mTorr to produce mainly CF_2 radicals. The amounts of CF_3 and F produced at the same time are reduced by an H component.

Since it is difficult to largely reduce the amounts of CF and O components in the radical forming plasma generating chamber **62**, an unnecessary component removing chamber **65** is provided downstream of the radical forming plasma generating chamber. In the unnecessary component removing chamber, an inner wall made of a material containing carbon or silicon such as carbon, Si, SiC or the like is provided to reduce the unnecessary components or to convert the unnecessary components into other gasses of less ill effect. A valve **71** is connected to an exit of the unnecessary component removing chamber **65** to supply a gas which is mainly composed of CF_2.

Since a large amount of sediment such as deposits is accumulated between the valve **70** and the valve **71**, it is necessary to perform cleaning or exchanging that portion in a comparatively short period. Therefore, in order to easily perform opening-to-atmosphere and exchanging work and to shorten vacuum build-up time at restarting, the portion between the valve **70** and the valve **71** is connected to an evacuation system **74** through a valve **72**. The evacuation

system **74** may also serve as an evacuation system for the processing chamber **10**.

The ion forming gas of a rare gas such as argon gas, xenon gas or the like indicated by B in the figure is supplied to the processing chamber through a valve **73**. The passage is connected to the exit of the valve **71**.

By maintaining the processing chamber **10** at a pressure of 5 to 50 mTorr and using the high frequency electric power source **16** having a modulated frequency above 20 MHz, a high density and low electron temperature plasma is provided having a density on the order of 10^{10} to $10^{11}/cm^3$ and an electron temperature of 5 eV, preferably, 3 eV, and dissociation of the ion forming gas is progressed while avoiding dissociation of CF_2 which requires a dissociation energy of 8 eV. As a result, on the surface of the sample **40**, the following reaction is mainly progressed with assistance of incident ions accelerated at several hundred volts by the bias electric power source **17**.

$$SiO_2+2CF_2 \rightarrow SiF_4\uparrow+2CO\uparrow$$

Since Si and SiN used as a base material are not etched by CF_2, it is possible to perform oxide film etching with a high selectivity.

Increases in the amount of fluorine due to partial dissociation of CF_2 can be decreased by virtue of the upper electrode cover **30** being made of silicon, carbon or SiC.

As described above, by adjusting the radical forming gas A and the ion forming gas B, the ratio of ions and radicals in the processing chamber **10** can be independently controlled, and consequently the reaction on the surface of the sample **40** can be easily controlled. Further, since unnecessary deposits are removed by the unnecessary component removing chamber **65** so as to enter the processing chamber **10** to as small a degree as possible, the amount of deposits in the processing chamber **10** is substantially reduced and accordingly frequency of cleaning the processing chamber **10** by opening to the atmosphere is also substantially reduced.

FIG. **40** shows a further embodiment in accordance with the present invention in which a quantity and a quality of ions and radicals are independently controlled. Hexafluoropropylene oxide gas (CF_3CFOCF_2, hereinafter referred to as HFPO) is passed through a heating pipe portion **66** via a valve **70** from the portion indicated by A in the figure, and through an unnecessary component removing chamber **65** and a valve **71**, and then mixed with an ion forming gas B to transfer toward the processing chamber **10**. In the heating pipe portion **66**, the HFPO is heated at a temperature of 800° C. to 1000° C. to form CF_2 by thermal decomposition expressed by the following chemical formula:

$$CF_3CFOCF_2 \rightarrow CF_2+CF_3CFO$$

Although CF_3CFO is comparatively stable and hardly decomposed, part of the CF_3CFO is decomposed to produce O and F. Therefore, the unnecessary component removing chamber **65** is provided downstream of the heating pipe portion **66** to remove the unnecessary components or convert to substances which will have ill effects. Although a part of the CF_3CFOCF_2 flows into the processing chamber **10**, there is no problem since it is not dissociated by the low electron temperature plasma below 5 eV.

Use of the valve **72** and the evacuating system **74** and reaction in the processing chamber is the same as described for the case of FIG. **39**.

The plasma processing apparatus having the electrostatic attracting circuit and the pulse bias voltage applying circuit in accordance with the present invention can be applied not only to an etching processing apparatus but also to a plasma processing apparatus such as a CVD apparatus by changing the etching gas to a CVD gas.

According to the present invention, it is possible to provide a plasma processing apparatus and a plasma processing method capable of easily performing precise working of a fine pattern to a large sized sample having a diameter of 300 mm or larger, and also capable of improving a selectivity during micro processing. Further, it is possible to provide a plasma processing apparatus and a plasma processing method capable of performing processing, particularly, oxide film processing all over the surface of a large sized sample uniformly and rapidly.

According to the present invention, it is possible to provide a plasma processing apparatus and a plasma processing method capable of improving the selectivity of plasma processing of insulator films such as SiO_2, SiN, BPSG and the like.

Further, it is possible to provide a plasma processing apparatus and a plasma processing method capable of improving the selectivity of plasma processing by obtaining a narrow ion energy distribution having better controllability. Furthermore, in a case of using a sample table having an electrostatic attracting dielectric layer, it is possible to provide a plasma processing apparatus and a plasma processing method capable of improving the selectivity of plasma processing by obtaining a narrow ion energy distribution having better controllability.

Further, it is possible to provide a plasma processing apparatus and a plasma processing method capable of easily performing precise working of a fine pattern and improving the selectivity during fine pattern processing. Furthermore, it is possible to provide a plasma processing apparatus and a plasma processing method capable of improving the selectivity of plasma processing of insulator films such as SiO_2, SiN, BPSG and the like by controlling the quantity and the quality of ions and radicals independently.

What is claimed is:

1. A plasma processing apparatus comprising a vacuum processing chamber, a plasma generating means including a pair of electrodes, a sample table having a sample mounting surface for mounting a sample to be processed inside said vacuum processing chamber, and a evacuating means for evacuating said vacuum processing chamber, which further comprises:

a high frequency electric power source for applying a high frequency electric power of a VHF band from 30 MHz to 300 MHz between said pair of electrodes; and

a magnetic field forming means for forming any one of a static magnetic field and a low frequency magnetic field in a direction intersecting an electric field generated between said pair of electrodes and the vicinity by said high frequency electric power source;

wherein an electron cyclotron resonance region being formed between said pair of electrodes by said magnetic field and said electric field.

2. A plasma processing apparatus comprising a vacuum processing chamber, a plasma generating means including a pair of electrodes, a sample table for mounting a sample to be processed inside said vacuum processing chamber and also serving as one of said electrodes, and a evacuating means for evacuating said vacuum processing chamber, which further comprises:

a high frequency electric power source for applying an electric power of a VHF band from 50 MHz to 200 MHz between said pair of electrodes; and

a magnetic field forming means for forming any one of a static magnetic field and a low frequency magnetic field not weaker than 17 gausses and not stronger than 72 gausses in a direction intersecting an electric field generated between said pair of electrodes and the vicinity by said high frequency electric power source;

wherein said magnetic field forming means being set so that a portion where a component of said magnetic field in a direction along the surface of said sample table becomes maximum is brought to a position in the opposite side of said sample table from the middle of said pair of electrodes;

an electron cyclotron resonance region being formed between said pair of electrodes by said magnetic field and said electric field.

3. A plasma processing apparatus according to any one of claim **1** and claim **2**, wherein

intensity of the magnetic field formed by said magnetic field forming means is set so that a component of the magnetic field parallel to the surface of said sample table is not stronger than 30 gausses on the surface of said sample table.

4. A plasma processing apparatus comprising a vacuum processing chamber, a plasma generating means including a pair of electrodes, and a sample table for mounting a sample to be processed inside said vacuum processing chamber and also serving as one of said electrodes, which further comprises:

a evacuating means for evacuating said vacuum processing chamber to 0.4 Pa to 4 Pa;

a high frequency electric power source for applying an electric power of a VHF band from 30 MHz to 300 MHz between said pair of electrodes; and

a magnetic field forming means for forming any one of a static magnetic field and a low frequency magnetic field not weaker than 10 gausses and not stronger than 110 gausses in a direction intersecting an electric field between said pair of electrodes and in the vicinity;

said electrodes being composed of a first electrode connected to said high frequency electric power source and a second electrode also serving as said sample table connected to a bias electric power source for controlling ion energy, a distance between said pair of electrodes being 30 to 100 mm;

an electron cyclotron resonance region being formed at a position within a range from the surface of said first electrode to the side of said first electrode from the middle of said pair of electrodes by interaction of said magnetic field and an electric field produced by said high frequency electric power source.

5. A plasma processing apparatus according to any one of claims **1**, **2** and **4**, wherein

density and/or direction of said magnetic field formed by said magnetic field forming means are adjusted so that said cyclotron resonance effect of electrons becomes larger in a portion within a range from the periphery of said sample to the outer side of the periphery than in the center of said sample, thereby the plasma density being made uniform in positions corresponding to all over the surface of said sample mounting surface.

* * * * *

Appendix C
Evidence Appendix

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicants:	T. KAJI, et al.
Application No.:	10/808,559
Filed:	March 25, 2004
For:	A PLASMA PROCESSING APPARATUS
Art Unit:	1763
Examiner:	M. Crowell

DECLARATION UNDER 37 CFR §1.132

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

I, **Shinichi Tachi,** do hereby verily declare that:

1. I received the Ph. D. degree in electronic engineering from Osaka University in 1979.

2. From 1979 until 1994 and from 1995 until 2002, I have worked as a member of the Central Research Laboratory, Hitachi, Ltd.

Additionally, I spent and worked for two years from 1994-1995 at headquarters of Hitachi, Ltd., as a planning and marketing officer. As a whole, I worked for 25 years in Hitachi, Ltd.

In addition, I moved to Hitachi High-technologies Co. in 2002 as a deputy general manager of Naka works. I established research and development division there in 2003. I am now an executive officer and general manager of Kasado works

of Hitachi High-technologies Co. The main product, which I have engaged in, is the plasma etching machine.

3. As a member of Scientific/Engineering Societies in the Central Research Laboratory, I had been engaged in developing plasma processing, ion beam technology, ion-solid interaction and semiconductor surface treatments.

Through many activities, I have participated in development of LSI chip processing by collaborating with many semiconductor device industries.

I have been a member of Japan Society of Applied Physics, Institute of Electrical Engineering of Japan, and American Vacuum Society,. and have worked as a committee member of International Dry Process Symposium for these 25 years, and was a chairman in 2003 and 2004.

4. In addition, I have written the following articles in my field:

(1) S. Tachi, M. Izawa, K . Tsujimoto, T. Kure, N. Kofuji, K. .Suzuki, R. Hamasaki, and M. Kojima, J. Vac. Soc. Technol. A16, 250 (1998).

(2) S. Tachi, M. Izawa, and M. Kojima, 1997 Dry Process Symp.

(3) M. Izawa, S. Tachi, R. Hamasaki, T. Yoshida, and M. Kojima, 1997 Dry Process Symp.

(4) M. Izawa, K. Yokogawa, S. Yamamoto, N. Negishi, Y. Momonoi, K. Tsujimoto, and S. Tachi, 1999 Dry Process Symp.

(5) Y. Gotoh, T. Kure, and S. Tachi, Jpn. J. Appl. Phys. 32, 3035 (1993).

(6) M. Mori, N. Itabashi, H. Ishimura, H. Akiyama, T. Fujii, G. Saito, M. Yoshigai, M. Kojima, K. Okamoto, K. Tsujimoto, and S. Tachi, Proc. SSDM 2000.

(7) N. Kofuji, T. Tsutsumi, E. Matsunmoto, K. Fujimoto, N. Itabashi, M. Izawa, T. Fujii, and S. Tachi, Proc. SSDM 2001 Symp.

(8) N. Kofuji, T. Tsutsumi, E. Matsumoto, K. Fujimoto, N. Itabashi, M. Izawa, T. Fujii, and S. Tachi, 2001 Dry Process Symp.

(9) K. Yokogawa, N. Negishi, S. Yamamoto, K. Suzuki, and S. Tachi, 1997 Dry Process Symp.

(10) N. Negishi, M. Izawa, K. Yokogawa, Y. Momonoi, T. Yoshida, K. Nakaune, H. Kawasaki, K. Kojima, K. Tsujimoto, and S. Tachi, 2000 Dry Process Symp.

(11) Masaru Izawa, Shinichi Tachi, and Nobuyuki Negishi, Reaction mechanism in plasma processing., The Vacuum Society of Japan, 2001.

5. I am one of the listed inventors in U.S. Patent Application Serial No. 10/808,559 (hereinafter referred to as "the above identified patent application".) I have carefully read the above-identified application including reviewing the drawings and the claims of the patent application. I have also carefully read the Office Action dated November 17, 2005, as well as USP 5,534,751 to Lenz and USP 5,272,417 to Ohmi.

6. With regard to the above-identified patent application, the specification states on page 40, line 8, et seq., that the discharge confining means, such as indicated by the numeral 37 in Fig. 1, is made of silicon, carbon or SiC. As noted on page 40, line 10 et seq., by virtue of the use of these materials:

> "When the discharge confining ring 37 is connected to a high frequency electric power source to cause sputtering by ions, it is possible to decrease attaching of deposits to the ring 37 and also to remove fluorine. "

<u>In each case of using either silicon, carbon or SiC, it is important to note that the material used is free of oxygen (unlike materials such as quartz and silica which both contain oxygen).</u> This avoidance of oxygen is very important in the construction of the discharge confining means, for reasons which will be discussed below. In addition, from further studies of the etching process by me and my co-inventors, we have now determined that making the discharge confining means of silicon has a substantial advantage, not only over materials such as quartz and silica, but also over other materials such as carbon and SiC.

Essentially, our studies have shown that the discharge confining means essentially constitutes a floating electrode during operation of the plasma apparatus. In particular, the discharge confining means has an electric potential on it during the plasma etching operation. As a result, the discharge confining means itself is etched by the plasma. If the discharge confining means contains oxygen, this etching of the discharge confining means will spread the oxygen into the plasma itself, thereby deteriorating plasma and the etching process itself.

In addition to excluding oxygen, we (that is, the inventors) have determined that forming the discharge confining means of the same material as the etched wafer

(specifically silicon) has the advantage that the etching of the discharge confining means itself will have no adverse effects at all on either the plasma or the etched wafer since material other than silicon will not be released into the plasma. Therefore, we have found that silicon is superior not only to materials such as quartz and silica which contain oxygen, but also to materials such as carbon and SiC mentioned as alternatives in the specification, since the etching of these materials will also release materials into the plasma different from the base material of the sample being etched.

With regard to the Lenz Patent, it is noted that column 6, lines 18 through 29 specifically states that the ring assembly 30 which serves as a confinement shield is made of high quality fused silica or quartz. Since both of these materials include oxygen, the Lenz discharge confining means will suffer the above noted problem that, during the etching process, the discharge confining means itself will be etched, thereby releasing oxygen into the plasma. Therefore, the etching of the wafer will be degraded, compared to the superior results which can be achieved using the invention disclosed in the above-identified patent application, specifically, by making the discharge confining means of silicon. In addition, it was noted that the secondary reference to Ohmi noted in the Office Action fails to add anything which would suggest modifying Lenz to make the discharge confining means of silicon, without oxygen.

I further declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false

statements and the like so made are punishable by fine, or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Further Declarant sayeth not.

2/10/06

Date

Shinichi Tachi

Appendix D
Related Proceedings App.

RELATED PROCEEDINGS:

1. **None**